FINAL REPORT

Do post-fire fuel treatments and annual grasses interact to affect fire regimes in the Great Basin?

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Abbreviations/Acronyms

ANOVA   Analysis of Variance
BLM   Bureau of Land Management
dNBR   Differenced Normalized Burn Ratio
MRPP   Multi-Response Permutation Procedure
MTBS   Monitoring Trends in Burn Severity
NMS   Non-metric Multidimensional Scaling
NPMR   Nonparametric Multiple Regression

Keywords

Rehabilitation, seeding, grazing, burn severity, fire regime, bunchgrass, plant community

Acknowledgements

Abstract

Shifting climates and annual grass invasions have contributed to the increased number and size of fires in the western United States costing millions of dollars in fire suppression and post-fire rehabilitation. Post-fire rehabilitation implements fuel treatments, such as aerial and drill seeding, to control annual grass invasion and alter fuels and subsequent fire behavior and effects. However, the effectiveness of these fuel treatments at a landscape scale is virtually unknown for Great Basin rangelands. Additionally, little is known about how grazing practices after rehabilitation affect perennial grass establishment and survival. Post-fire rehabilitation treatments, post-fire grazing, as well as burn severity, will likely affect plant responses to these disturbances. ***This project investigated 1) the impact of post-fire fuel treatments (seeding) on post-fire community trajectories, fuels composition, and fire return intervals, 2) the effects of livestock grazing on seedling and community recovery, and 3) how burn severity relates to post-fire recovery in the Great Basin.***

To assess the effects of aerial and drill seeding on plant community trajectories, fuel composition, and fire regimes, we collected geospatial datasets spanning 209,000 ha of sagebrush steppe on BLM land in southern Idaho. In the field, we sampled fuel and plant community composition by sampling 68 sites in 2014 and 2015 across areas that had burned 1-6 times and had no, aerial, drill, or aerial + drill seeding. We found that 1) fire and rehabilitation shaped plant communities, 2) drill seeding after multiple fires in dry, low elevation sites prevented conversion to cheatgrass-dominated systems, 3) drill seeded sites had fewer fires and increased in fire frequency more slowly than aerial seeded sites, 4) the on-the-ground conditions that led to the decision to aerially seeding after a fire led to more frequent and numerous fires.

To examine the effects of post-fire grazing on seedling establishment, we varied surrounding plant communities around target bunchgrasses by removing either neighboring adult or seedling grasses. Grazing was simulated by clipping plants either in the dormant or growing season one or two years after fire. Timing of senescence, plant growth and survival were measured for three years after wildfire. We found that 1) seedling removal delayed senescence and decreased seedling cover and density, 2) spring defoliation led to negative effects for both within- and across-season metrics, 3) delaying defoliation from year one to two decreased negative effects on seedling growth, and 4) seedling survival did not vary by either neighbor removal or defoliation.

We also used the Monitoring Trends in Burn Severity (MTBS) database to 1) quantify area burned in the Great Basin and identify regional hotspots, 2) characterized burn severity classes across vegetation types, and 3) examine cover types in relation to burn severity one year after fire. We found that 1) over 8 million hectares has burned with some areas burning seven times from 1984-2016, 2) burn severity values varied across vegetation type, and 3) annuals and char increased with burn severity while soil decreased with increasing burn severity.

Our results provide managers with knowledge of 1) the effects of post-fire fuel treatments on plant community trajectories and subsequent fire regimes across climate and environmental gradients, and 2) the effects of grazing on perennial bunchgrass establishment after post-fire seeding, and 3) the use of burn severity indices in rangelands. Results will provide insight into the most effective use of limited fiscal and labor resources and contribute to maintaining sustainable rangelands that are resilient to fires and resistant to annual grass invasion.

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Background

Globally, wildfire size and frequency has increased in the last thirty years across numerous ecosystems (Goetz et al. 2007) and studies are projecting that high intensity fires in these and neighboring systems will increase in frequency in the future (Barbero *et al.,* 2015; Abatzoglou & Williams, 2016). The area burned on Bureau of Land Management (BLM) land in Idaho from 2000 to 2010 was over three times greater than that burned in the 1970s. Shifting climates and annual grass invasions have contributed to the increased frequency and size of fires in the western United States costing millions of dollars in fire suppression and post-fire rehabilitation. Models predict continued changes in fire regimes (Liu et al. 2010).

The invasive annual grass, cheatgrass (*Bromus tectorum*), has altered the historical fire regime in the Great Basin leading to profound changes in fire size, frequency, and duration (Balch et al. 2013). Cheatgrass recruits well after disturbance and fires (West and Hassan 1985, Peterson 2005) and creates continuous, highly flammable fuels that aid the spread of fire (Brooks et al. 2004) promoting further recruitment. Even low cheatgrass cover will increase the chance of adjacent habitat burning in subsequent fires (Link et al. 2006, Bradley et al. 2018). Models suggest that climate change will increase the risk of cheatgrass invasion in Idaho, Montana, and Wyoming (Bradley 2009) making a reduction in cheatgrass cover and resistance to future cheatgrass recruitment an important goal of many fuel treatments in the Great Basin (Baker 2006).

Post-fire fuel treatments aim to decrease the spread of invasive species and thus subsequent fire; the BLM's post-fire Emergency Stabilization and Rehabilitation (ESR) program often includes seeding as a way to reduce cheatgrass cover and density by controlling fuels composition. The most common seed application methods are drill and aerial seeding or a combination of the two. Greenhouse and small-plot experiments show that bottlebrush squirreltail (*Elymus elymoides)* (Booth et al. 2003), Sandberg bluegrass (*Poa secunda)* (Goergen et al. 2011), crested (*Agropyron cristatum*) and desert (*A. desertorum*) wheatgrass (Aguirre and Johnson 1991, Arredondo et al. 1998, Yoder and Caldwell 2002) can reduce the growth, reproduction, or recruitment of cheatgrass and are added to seed mixes. However, we know little about how effective post-fire fuel treatments are at reducing annual plant invasions across landscapes, particularly in rangelands. Attempts to synthesize the effects of fuels treatments on fire severity, fire behavior, and subsequent fuels in rangelands have been limited to a few small-scale experiments (Hudak et al. 2011, Martinson and Omi 2013).

The efficacy of post-fire fuel treatments is important for ecosystem function, future fire regimes, wildlife habitat, and livestock use. Domestic livestock grazing is an important economic land use in the Great Basin, and land managers make an effort to reintroduce livestock in a timely manner after wildfire. Perennial bunchgrasses require time to recover to pre-fire conditions (Knutson et al. 2014), and improper domestic livestock grazing can be detrimental to recovering plant communities after fire (Pellant et al. 2004). Livestock grazing is typically postponed for two growing seasons after wildfire to allow for plant species recovery (BLM 2007); however, there is little research addressing the effects of timing of post-fire livestock grazing on perennial bunchgrass seedlings planted in post-fire restoration treatments.

This project investigated 1) the impact of post-fire fuel treatments (seeding) on post-fire plant community trajectories, fuels composition, and fire return intervals, 2) the effects of livestock grazing on seedling and plant community recovery, and 3) how burn severity relates to post-fire recovery in the Great Basin. We used a combination of fieldwork, remote sensing, and GIS analysis to examine the relationships between fuels treatments, grazing, burn severity, and plant community recovery. This allowed us to determine if post-fire fuel treatments in semi-arid rangelands achieve their goals and how post-fire livestock grazing affects treatment effectiveness.
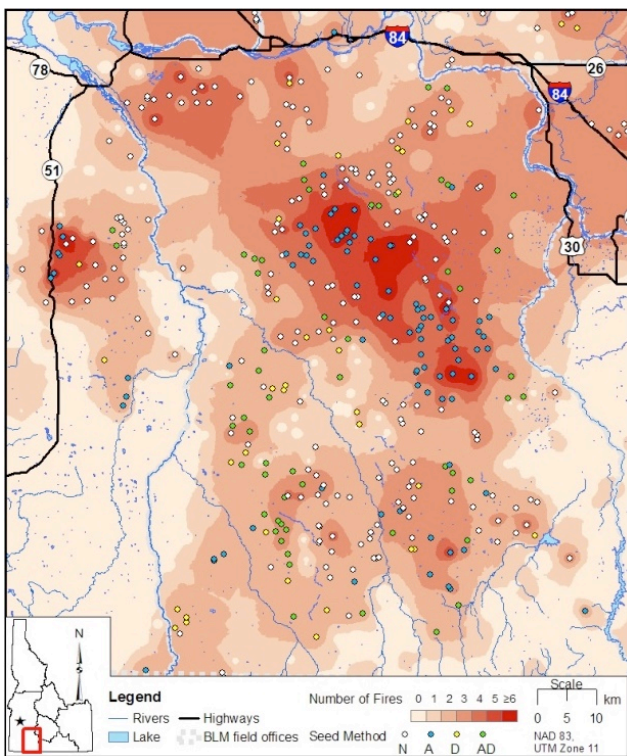

Figure 1 Fire frequency based on an inverse distance weighted analysis of the original 1200 random points. Circles represent the 412 data extraction points and the treatment each represented. Sites with multiple fires have overlapping circles that cannot be viewed. Spatial autocorrelation was strong for the number of times an area has burned and treatments (especially aerial seeding). N = not seeded, D = drill seeded, A = aerially seeded, AD = aerial and drill seeded.

Project Objectives, Methods, and Results

1. Effects of post-fire fuel treatments on community trajectories, fuels composition, and fire return intervals.

Methods

In 2013, we collected geospatial datasets spanning 209,000 ha of sagebrush steppe on BLM land in southern Idaho. We compiled spatial data on rehabilitation treatments from Inside Idaho, BLM field offices, and the USGS Land Treatment Data Library. We obtained BLM fire historical perimeters from Inside Idaho. We created 2,000 random points throughout the study area (ArcGIS 10.1) and eliminated sites that were in water bodies, agricultural fields, and on private property. We extracted fire history (Figure 1) and rehabilitation history at the remaining 1000 points. We then organized prospective sites by fire number and most recent rehabilitation method. We chose treatment combinations based on the number of times burned (0, 1, 2, 3, 6) and whether they were drill seeded (D), aerially seeded (A), or not seeded (N) after the most recent fire.

Site Information Database:

We created a site information database by compiling data on environmental, fire, and rehabilitation data. This detailed database was not used to select sites but is being used in multivariate analyses with plant community data.

Fuel/Plant Community Composition:

We sampled 68 sites in 2014 and 2015 for plant community composition along three 30 m transects (180 m^2 area per site). We collected fuel composition based on plant cover using line-point intercept. We estimated plant density of fuels using five-1 m^2 quadrats along each transect (total of 15 quadrats per site). We used a multivariate analysis to model the effect of environmental, fire, and rehabilitation variables on fuels composition by species, cover, density, and fuel load. We used a Multi-response Permutation Procedure (MRPP) to test for differences among treatments.

Fuel Load:

We sampled the same 68 sites in 2014 and 2015 for fuel loads. We estimated fuel load by collecting biomass from six-1 m^2 plots per site. Clipped plants were sorted into shrub, forbs, perennial grass, or annual grass.

Effectiveness Over Time:

In 2015 we randomly sampled 1,100 locations and extracted fire and treatment history. We then used data on treatment and fire on sites with two or more fires so we could test the effect of fire number and treatment type on the fire return interval between subsequent fires. This resulted in an analysis of 412 treatment and fire combinations using fire and rehabilitation history as predictor variables in a two-way, mixed-model ANOVA. We used fuel composition and load data (see above) to determine the impact of time since rehabilitation on maintaining low levels of cheatgrass.

We analyzed the effect of 99 variables on the total number of fires that have occurred at a site and the fire frequency and fire return interval over the past twenty years using a Nonparametric Multiple Regression (NPMR). We also used an NPMR to analyze the effect of 56 variables on cheatgrass cover on our field sites and determine the variables that explain the greatest degree of variation in our data.

Table 1 Percent cover of dominant cover types for treatments indicated as significantly different by the MRPP.

Cover Type	Unburned, Untreated	Unburned, Drilled	Burned & Treated
P. secunda	33	26	18
Other native bunchgrass	3	3	3
A. tridentata wyomingensis	24	11	0
A. cristatum	0	11	21
Forbs	0.7	0.3	1.5
B. tectorum	6	2	21
Moss	20	10	6

Results

Site Information Database:

The site information database with abiotic environmental and site history variables is complete. The PRISM data indicated precipitation varied from 220-364 mm among sites; elevation ranges from 780-1790 m. The first time a site burned ranged from 1958 to 2012 with 32 sites burning for the first time between 1970-1989. The most recent fire for the majority of sites occurred in the last 16 years. For sites with two or more fires, the time between the two most recent burns ranged between 1-34 years.

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Fuel/Plant Community Composition:

We collected plant cover and density data for all 68 sites in 2014 and 2015. The most common plants were Sandberg bluegrass (*Poa secunda*; 66 sites), crested wheatgrass (*Agropyron cristatum*) and sagebrush phlox (*Phlox aculeate;* 45 sites), tumble mustard (*Sisymbrium altissimum*; 37 sites), Russian thistle (*Salsola tragus*; 35 sites), bottlebrush squirreltail (*Elymus elymoides*; 30 sites) and bluebunch wheatgrass (*Pseudoroegneria spicata*; 22 sites). Analyses showed there was no difference among years so data were pooled across 2014 and 2015.

Fuels composition within sites with a similar fire number and recent post-fire treatment were more homogenous than expected by chance indicating that plant community and, thus, fuels composition are not the result of random processes. Despite this, using fire and immediate post-fire rehabilitation to categorize sites resulted in poor differentiation among treatments. Fuels composition as calculated by plant cover differed among unburned sites with no history of vegetation treatment (0N) and all other sites. Unburned, previously drill seeded sites (0D) were significantly different from sites aerially seeded after one and three fires (1A, and 3A, respectively) while there was a trend toward significance between 0D and the other treatments. Burned, sites were typically not different from one another, but there was a trend toward significance for seven of the 55 burned, treatment comparisons. Cover of *P. secunda*, moss, and *A. tridentata wyomingensis* decreased with treatment and fire while cover of forbs, *A. cristatum,* and *B. tectorum* increased (Table 1). These data suggest one of two possibilities.

First, there may have been wide variation among sites with similar numbers of fire and types of recent post-fire rehabilitation. Second, the effect of fire and drill seeding are similar and create indistinguishable fuels composition. We believe the former is more likely since our sites were spaced along the elevation and climatic gradient. The variation in plant community among sites with the same number of fires and recent treatment type is apparent in the nonmetric multidimensional scaling (NMS) ordination. Many species had strong relationships with elevation and climate (Figure 2). *Bromus tectorum* cover and density was greatest at warm and dry, low elevation sites. *Agropyron cristatum* cover and density was not strongly correlated climate but was correlated along the second axis that, for cover, was associated with increasing numbers of rehabilitation treatments and shorter periods between fires. *Poa secunda* cover was slightly greater with an increase in elevation, but unaffected by treatment of fire history. The cover of other native perennial bunchgrasses were strongly influenced by climate, with greater cover and density at cooler more mesic, higher elevation sites with little impact by rehabilitation. Dominant vegetation is highlighted in large gray letters (Figure 2) and will be used in subsequent figures to denote dominant vegetation in ordinations with fire and rehabilitation. The NMS ordination illustrated the considerable within-treatment variation as overlapping plant communities and, thus, fuels composition (Figure 3). This variation was due in large part by the climate and to a lesser extent Vetand fire history (Figures 2 & 3).
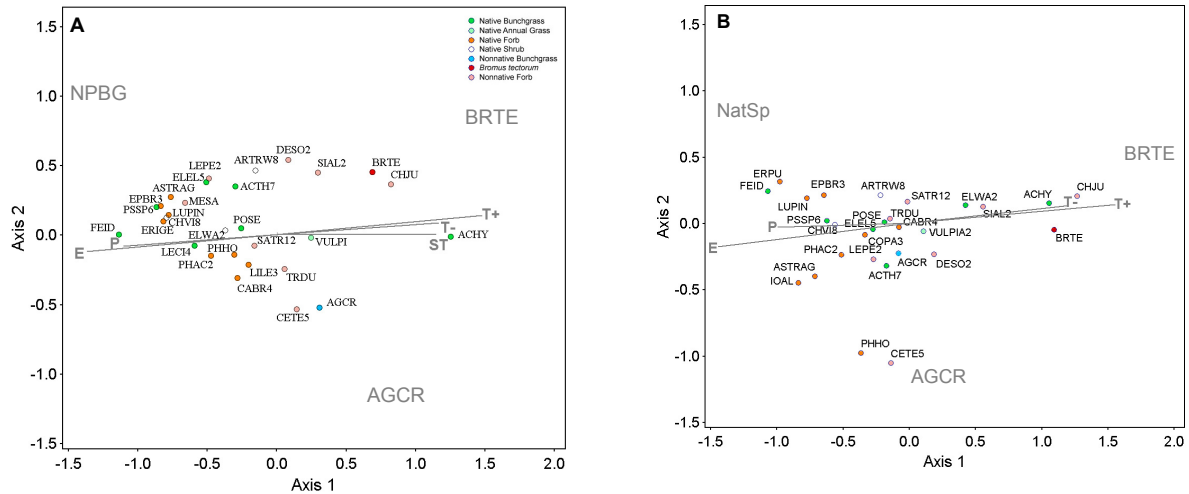
Figure 3 The NMS ordination based on plant cover (A, C, E) and density (B, D, F) grouped by the number of fires (0, 1, 2, 3, 6) and the type of rehabilitation seeding done after the most recent fire: none (A, B), aerial seeded (C, D) or drill seeded (E, F). Joint biplot of variables represents axis correlations (r2 ≥ 0.3) for maximum (T+) and minimum (T-) temperature, precipitation (P), elevation (E) and soil texture (ST). Lette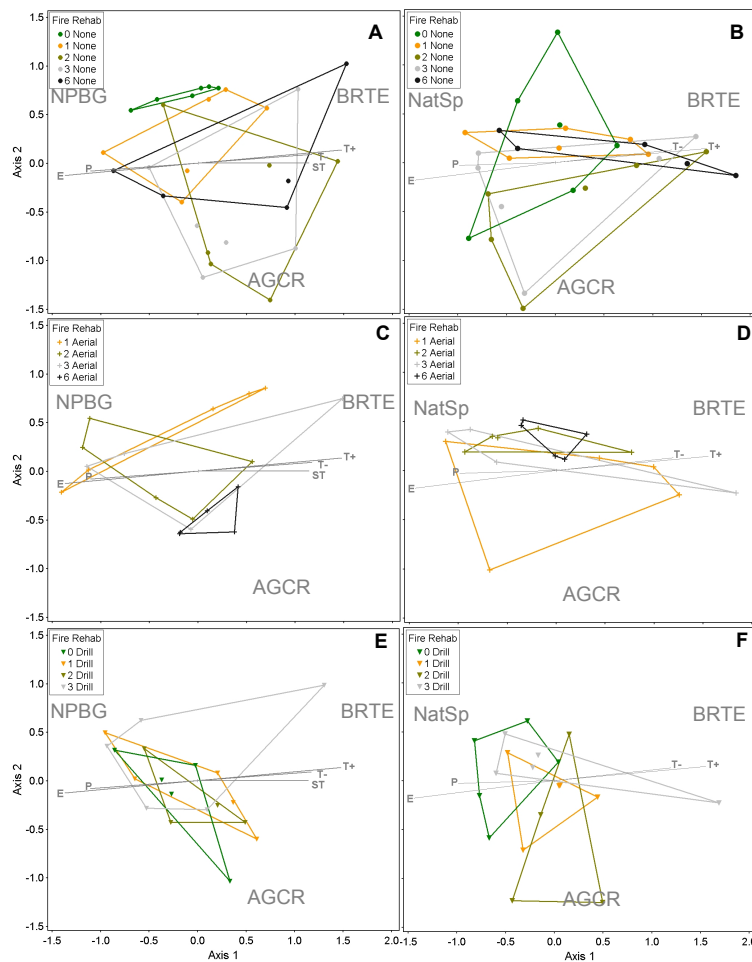rs in gray indicate the dominant vegetation in each quadrant: Native perennial bunchgrass (NPBG), *Bromus tectorum* (BRTE), *Agropyron cristatum* (AGCR), or Native forbs and grasses (NatSp).

We also tested whether dividing sites into fire-rehabilitation treatments within elevation categories would improve the differentiation among treatments (Figure 4). In general, low elevational sites were dominated by either *B. tectorum* or *A. cristatum* depending on fire and post-fire rehabilitation history. Sites at higher elevations were dominated by either native perennial bunchgrasses or *A. cristatum*, depending on the species seeded at the time of post-fire rehabilitation.
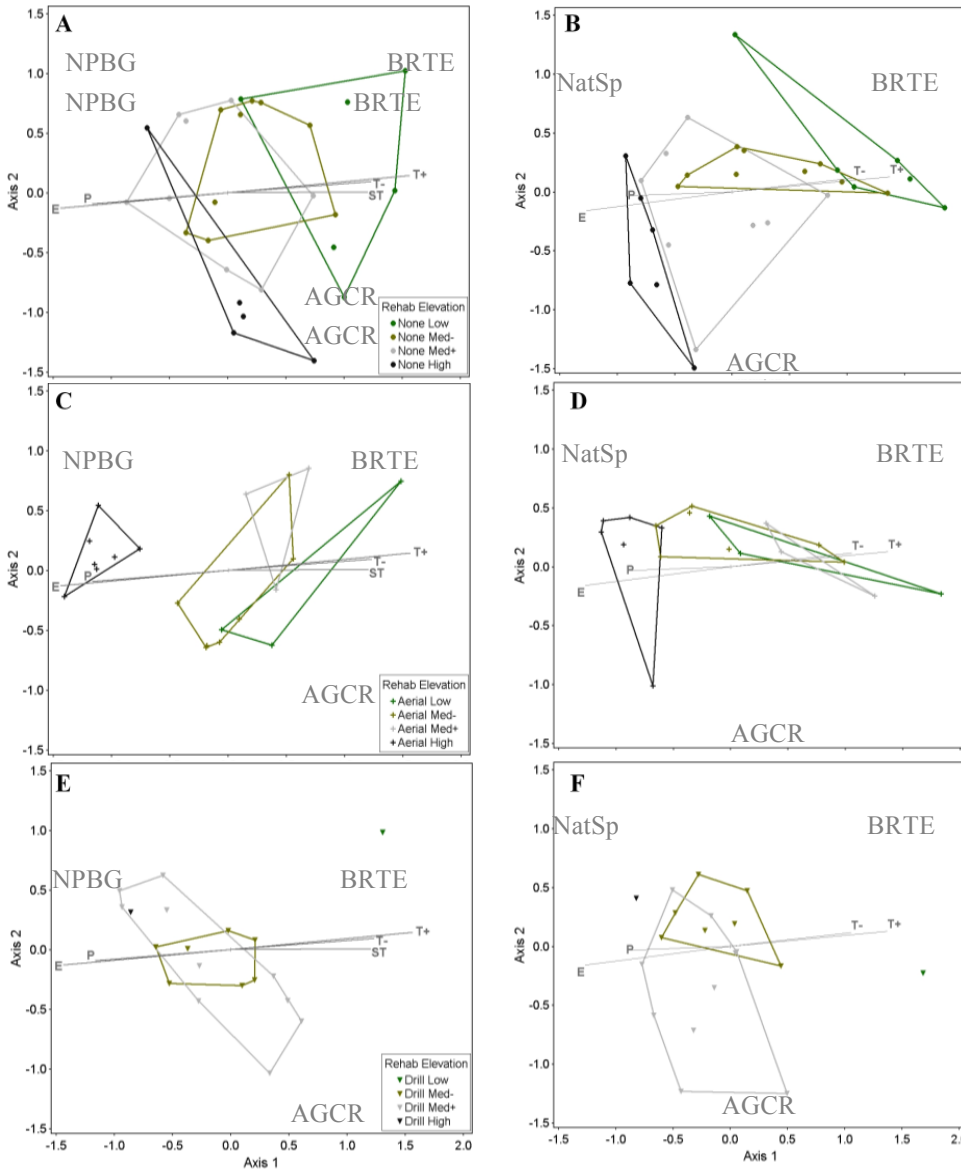
Figure 4 NMS ordination with sites grouped by most recent post-fire rehabilitation action and elevation for plant cover (A, C, E) and density (B, D, F). Letters in gray indicate the dominant vegetation in each quadrant: Native perennial bunchgrass (native perennial bunchgrass), *Bromus tectorum* (BRTE), *Agropyron cristatum* (AGCR), or Native forbs and grasses (NatSp).

Ordinations grouping sites within elevation regions suggested that the effect of fire and vegetation treatment history varied along elevational gradients (Figure 4). At low elevations, *B. tectorum* cover increased with fewer post-fire rehabilitation treatments and long durations between fires (Figure 4). At intermediate elevations, sites with well-established perennial

bunchgrass communities may be less susceptible *B. tectorum* invasion; however, if a site burned before a drill seeded site was able to establish, then *B. tectorum* was able to invade (Figure 4). At higher elevation sites, post-fire rehabilitation had little effect on the chance of cheatgrass invasion (Figure 4) due to unsuitable climatic conditions, but a history of drill seeding resulted in well-established Agropyron dominated communities.

Fuel Load:

Fuel load composition did not differ among rehabilitation treatments. Biomass differed along the elevational gradient, but sites within elevation bands were not similar in their functional group biomass. Fuel load composition was more similar among treatments within a similar elevation range then they were with other sites with similar post-fire rehabilitation treatments at other elevations. Shrub density increased significantly as elevation increased, but annual grass biomass decreased as elevation increased (Figure 5). There was a trend toward a significant decrease in forb biomass and an increase in perennial bunchgrass as elevation increased (Figure 5). There was considerable variation in fuel loads within treatment type and at similar elevation. This could be the result of differences in time since most recent fire, success of plant establishment after treatments, or environmental differences, such as differences in soil type.
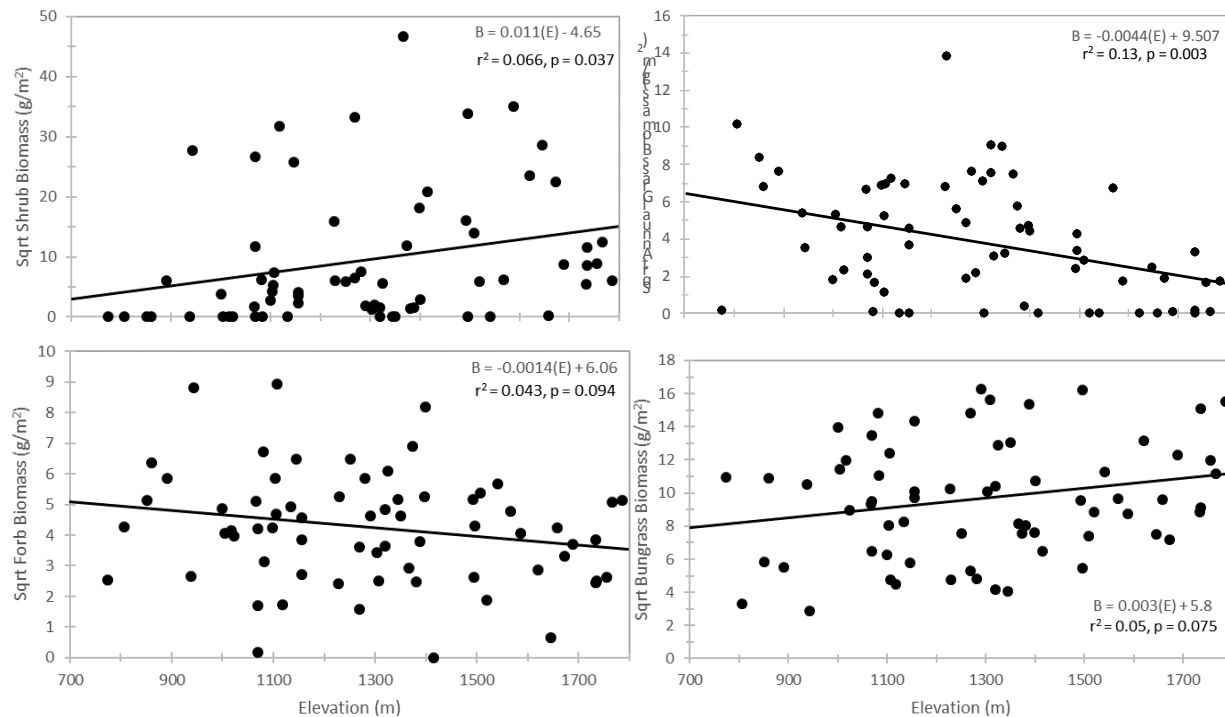

Figure 5 Biomass scatter plots showing the relationship between elevation and the square root of the biomass of each functional group: shrub (A), annual grass (B), forb (C) and perennial bunchgrass (D). Lines indicate the linear regression slope.

Treatment Effect Over Time:

Our analysis suggests a complicated relationship between fire history, rehabilitation, and

cheatgrass cover. Pooling sites that varied in the number of burns, cheatgrass cover decreased with time since fire. There was a threshold of 10 years required between fires before cheatgrass cover was consistently below 10% cover, however, the linear relationship was weak. There was a slight, nonlinear relationship between time since last rehabilitation treatment that varied with elevation, resulting in increasing cover and density at lower elevations but decreasing cover and density at higher elevation.

Seeding with greater bunchgrass diversity was more likely to inhibit fine fuels created by annual grasses like *B. tectorum*. Pooling total bunchgrass cover explained more variation in *B. tectorum* cover than using temperature or *A. cristatum* or *P. secunda* cover in a linear analysis (Figure 6). Native perennial bunchgrass cover had a nonlinear relationship with *B. tectorum* cover and was most prevalent between 1200 and 1400 m (Figure 7). There were no linear relationships between *B. tectorum* cover and elevation and time since recent rehabilitation treatment (Figure 7). Fine fuels from *B. tectorum* cover increased between 1000-1400 m then decreased with elevation. Below 1200 m standing fine fuels increased with time since fire, but above 1200 m *B. tectorum* cover decreased with time since rehabilitation treatment.
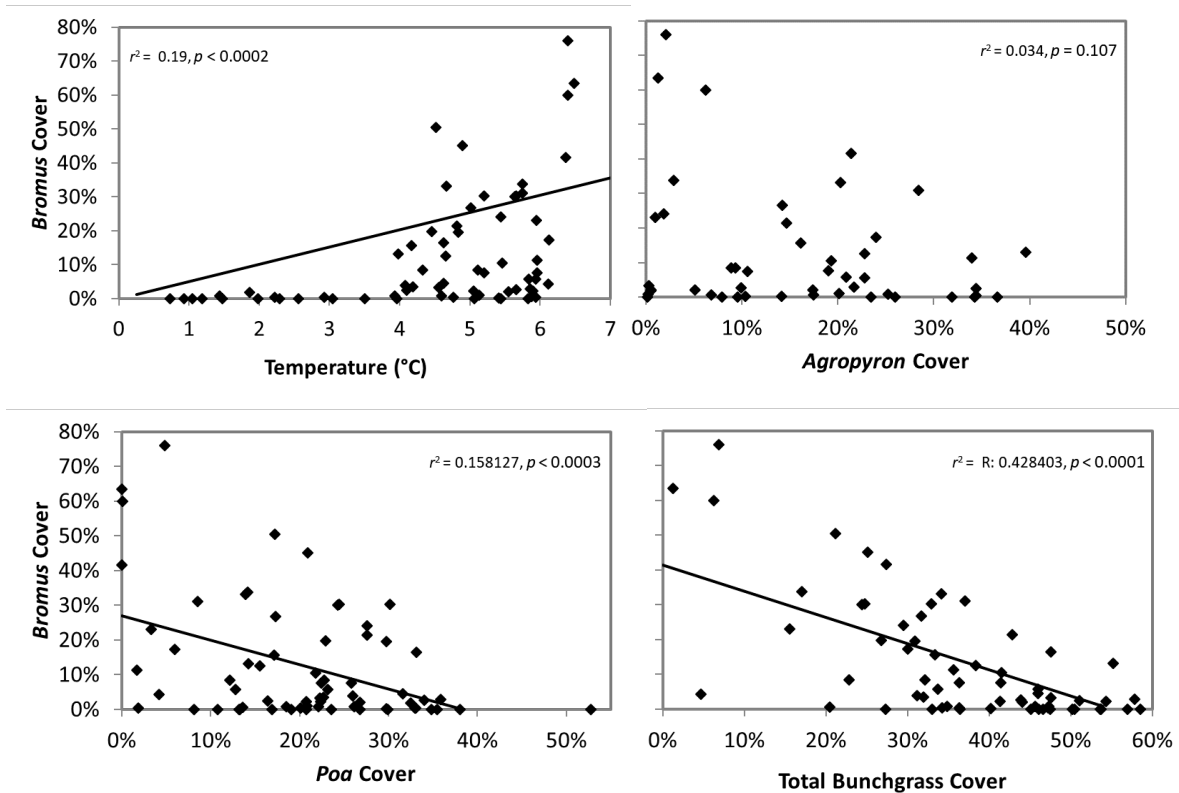

Figure 6 Scatter plots showing linear regression plotted for the effect of the proportion of cover for PRISM average minimum annual temperature (A), *Agropyron cristatum* (B), *Poa secunda* (C), and all bunchgrass species, excluding *P. secunda*, (D) on *Bromus tectorum* cover.
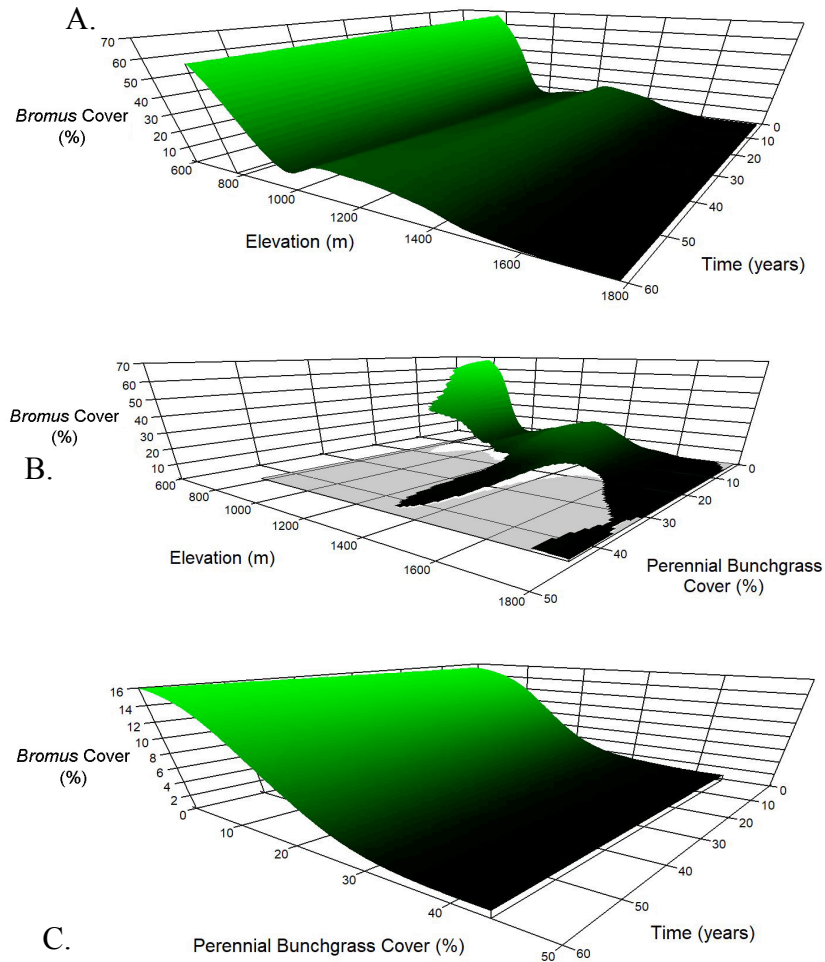
Figure 7 NPMR modeled relationship for *Bromus tectorum* cover when native perennial bunch grass cover and density was included in the predictor matrix for A) Elevation and time since last treatment, B) Elevation and bunchgrass cover, and C) bunchgrass cover and time since last treatments. Treatment includes any vegetation or post-fire rehabilitation. Gray areas in the predictor space represent areas where there were insufficient sites to models the relationship.

A landscape level analysis of treatment and fire history suggested a possible reason for the shift in cheatgrass cover over time among sites with varied fire history. The fire return interval after three fires in the Jarbidge Field Office is ≤ 10 years regardless of post-fire rehabilitation treatment. Untreated sites after three or more fires had fire return interval of 5-10 years, while aerially seeded sites had a fire return of 3-5 years. After three fires, the only post-fire rehabilitation treatment applied was aerial seeding or none, so it was not possible to address whether drill seeding after four or more fires would increase the fire return interval.

Climate and rehabilitation treatment type effected fire regimes in our study area. Climate impacted fire regimes in our study area predictably with wetter *Artemisia tridentata wyomingensis* sites having fewer fires. Types of post-fire rehabilitation altered fire regimes

differently. Sites with aerial seeding had more fires since 1955 and greater fire frequency over the last 20 years. Additional aerial seed treatments correlated with increases in fire frequency with each seeding. Drill seeded treatments did also increased fire frequency over the last 20 years, but at a much slower rate. It seems that the on-the-ground conditions that lead to the decision to aerially seed result in more frequent fires. In our study area, aerial seeding sagebrush or other plants is commonly used on sites where fire resilient bunchgrass species *Agropyron cristatum* or *Elymus wawawaiensis* have established. It is possible that these systems could be more prone to fuels build up and subsequent fire.
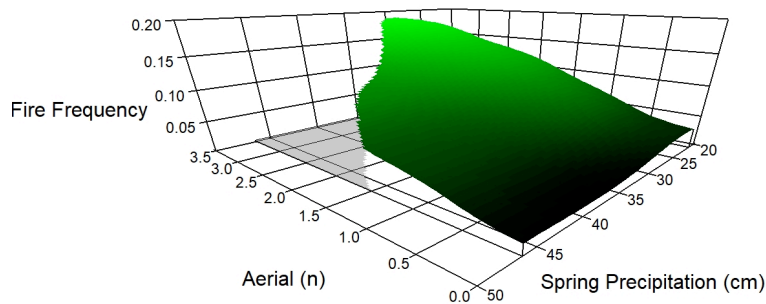
Figure 8 The NPMR modeled effect of spring precipitation on fire frequency in the last 20 years. As moisture increased, fire frequency decreased, but fire frequency increased with each aerial seeding in all climates.
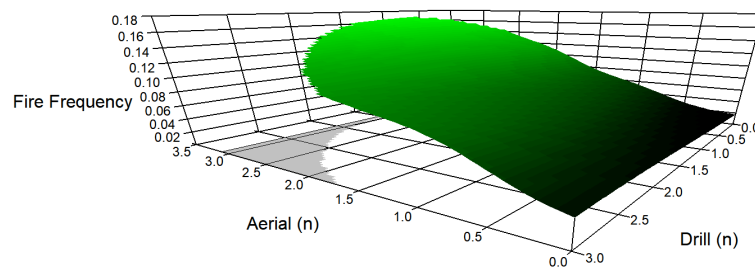
Figure 9 The NPMR modeled effect of aerial and drill seeding treatment on fire frequency in the last 20 years. Drill seeding increased fire frequency slight, but fire frequency increased much quicker on aerial seeded sites.
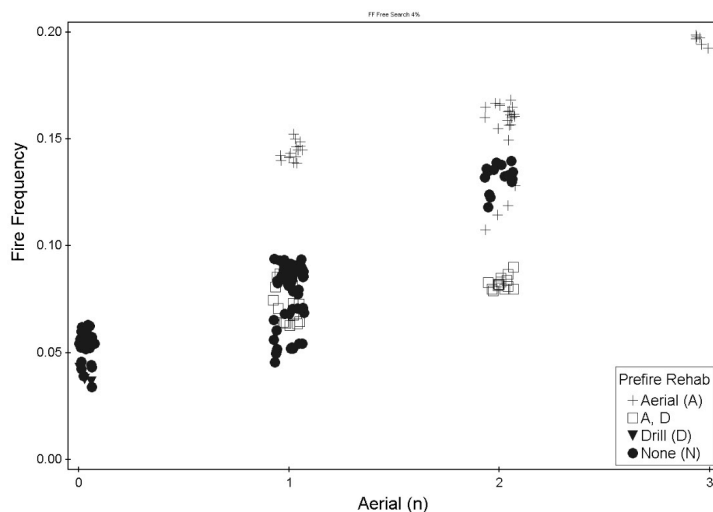
Figure 10 Modeled effect of treatment history on fire frequency. The number of aerial seed treatments increased fire frequency regardless of the other treatments used, however, drill seeding or leaving sites unseeded did lead to a decrease in the effect of aerial seeding on fire frequency.

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2. Grazing effects on fuel composition and seedling establishment.

The *Spatial Pattern* and *Neighborhood x Grazing* experiments focused on grazing effects on seedling establishment and resulting fuel characteristics. The latter two experiments examined the "two-year" rule for rest after fire commonly applied by the BLM (BLM 2007). These two experiments were conducted on the Coleman Fire (northwestern Nevada) in the BLM Applegate Field Office and the Saddle Draw Fire (southeastern Oregon) in the BLM Vale District Office.

The *Spatial Pattern* experiment assessed changing spatial patterns of bunchgrass seedling establishment over the first three years after fire in the absence of grazing. Vegetation spatial patterns affect future community dynamics, and the density and location of seedlings in relation to surviving adults may determine future community structure. We expected seedling density and percent cover to vary inversely with those same metrics for surviving adult grasses due to direct resource competition. We also expected seedling patchiness associated with drill rows to increase in spatial scale when grazing is eventually reintroduced on these sites due to grazing disturbance (Rayburn and Monaco 2011).

The *Neighborhood x Grazing* experiment examined how simulated livestock grazing affects seedling growth and survival rates under different plant-plant scenarios. Community composition directly affects species interactions, and under harsh environmental conditions, facilitation may play an important role for seedling establishment (Bertness and Callaway 1994). Different plant community neighborhoods were simulated by removing either surviving adult or seedling bunchgrasses. Within these modified neighborhoods, grazing was simulated at different time since fire to determine the effect on seedling growth and survival rates.

Methods

Spatial Pattern Experiment: Twelve-1 m^2 spatial mapping plots were established in spring 2015 at each field site using a random grid-cell method. Plots contained both surviving adult and seeded perennial bunchgrasses and were surrounded fenced for protection against grazing. Basal and canopy cover of all individual plants were mapped to 1cm accuracy and digitized for spatial analysis. We mapped foliar and basal cover of all plants within each plot during peak greenness to 1 cm accuracy using a 1-dm^2 gridded quadrat (Figure 11). Seedlings were identified to species and age class for grasses (surviving adult vs. seedling) from surviving adults for analysis by species and age classes. Maps were scanned and digitized into ArcGIS. Data was analyzed for density, percent foliar and basal cover, and spatial distribution by species, functional group, and age class. Plots were remapped through the third growing season after fire; data were analyzed across years to determine spatial trends.
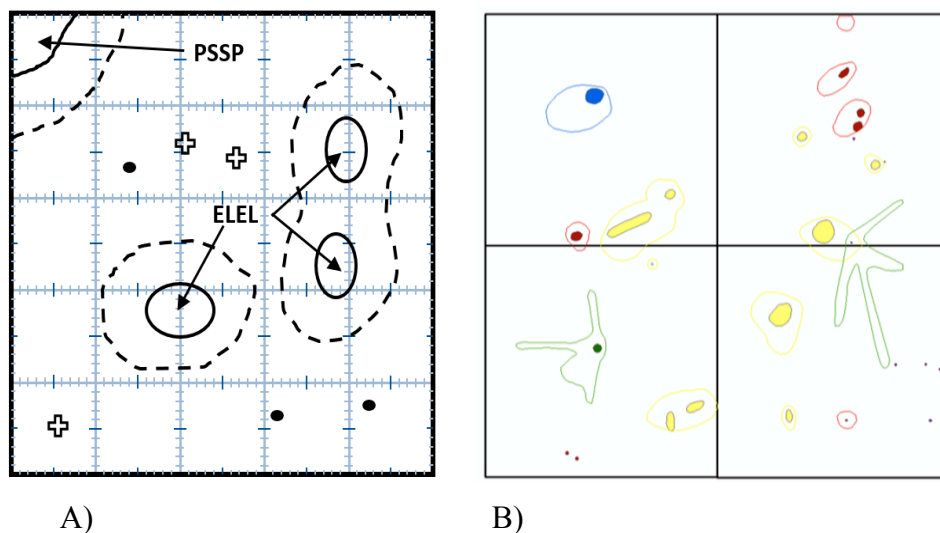
A)   B)

Figure 11 A) Hypothetical mapped 1-dm^2 quadrat. B) Actual mapped quadrat from 2015.

Neighborhood x Grazing Experiment:

Neighbor removal macro-plots were established in spring 2015 at each of the Coleman and Saddle Draw field sites using a random grid-cell method. We applied one of three neighbor removal treatments on each macroplot with four grazing treatments nested within neighbor treatments. Each macroplot was replicated six times (18 macroplots total) and was fenced to exclude livestock grazing.

Treatment levels:

Neighbor Removal (macro-plot type)	*Simulated Grazing (sub-plot type)*
None (control)	None (control)
Adult Removal	Fall Year 1 (2015)
Seedling Removal	Spring Year 2 (2016)
	Fall Year 2 (2016)

3 x 4 = 12 total treatments

For neighbor removal treatments, either all adult or all but four seedling bunchgrasses within each 1m^2 treatment plot were cut just below the root crown. Neighbor removal treatments were maintained each spring and fall. Simulated clipping treatments used a 50% utilization level (50% of above ground biomass clipped) and all clipped biomass was removed from the plot.

We opportunistically added six spring year one grazing treatment plots at each site, as livestock were present on both sites. These plots were all grazed by livestock during the growing season; however, not all grasses within each plot were grazed. For ungrazed bunchgrasses in these plots, we implemented a one-time 50% utilization clipping treatment during Aug. 7-10, 2015 to approximate utilization on those grasses that were grazed by livestock. We then randomly selected four seedlings within each plot. We marked these seedlings with colored wire

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for growth and survival measurements starting in 2016.

Three seedlings per plot and two tillers per seedling were marked with colored wire each growing season. Within-season timing of senescence, inflorescence production, and across-season seedling survival were measured to quantify plant-level treatment effects. Total perennial bunchgrass cover and density were measured using ocular assessments to quantify community-level treatment effects. Measurements were repeated through the third growing season after fire.

Results

Spatial Pattern Experiment: We mapped plots in July 2015, 2016, and 2017. Data from 2015 and 2016 have been analyzed as of September 2018. Preliminary results indicate that perennial bunchgrass and annual foliar cover, total species diversity, and total species richness all increased with time (Figure 12 & 10). Seedlings were both highly clustered within drill furrows and evenly spaced between furrows in the first year after fire; however, seedlings became less clustered within furrows and spacing between furrows became less detectable by the second year after fire (Figure 14A). We detected dispersive effects of adult perennial bunchgrasses on seedlings in the second year after fire (Figure 14B). Additionally, neighbor density appears to be the main factor controlling seedling growth and survival within the first two years after fire; however, bunchgrass species differ in their responses to increasing neighbor density, thickspike wheatgrass (*Elymus lanceolatus*) exhibited little sensitivity to neighbor density for seedling survival, while bottlebrush squirreltail and bluebunch wheatgrass exhibited negative neighbor density dependence. All species exhibited negative effects of increasing neighbor density on year one and two end-of-season size (data not shown).
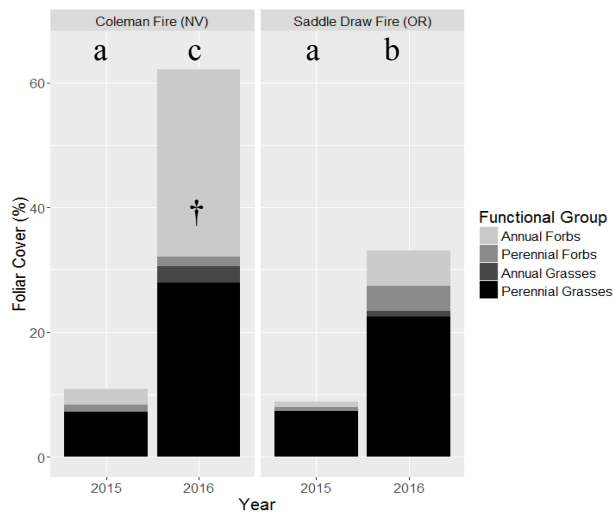
Figure 12 Mean foliar cover by functional group, site, and year. All functional groups summed represent total foliar cover. Letters represent statistically significantly different groups for total foliar cover among years and sites, * represent significant differences for a particular functional group within site across years for a particular functional group within site, and † represent significant differences for a particular functional group across sites within year. All comparisons are statistically significant at $\alpha = 0.05$. Symbols are only shown on the group with a higher mean but represent the appropriately paired group.
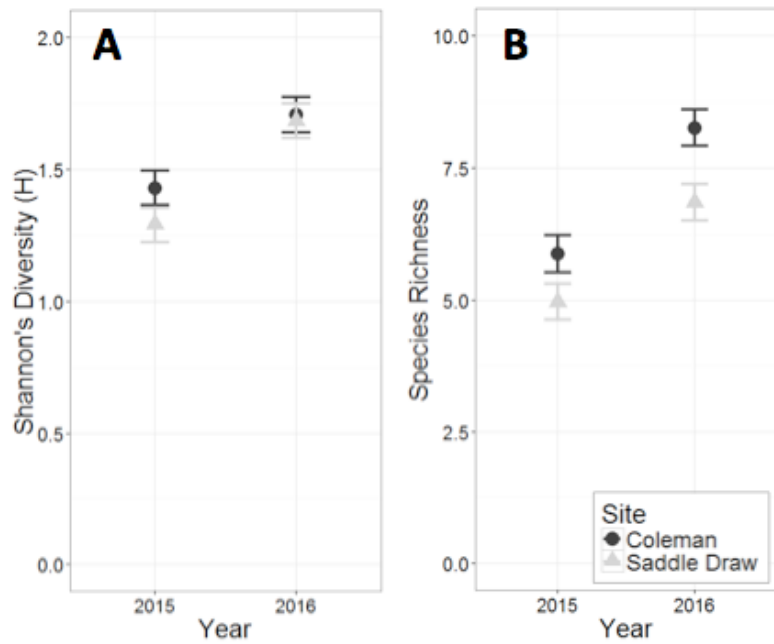
Figure 13 A) Shannon's diversity and B) species richness by site and year. Points represent model estimates with standard errors.
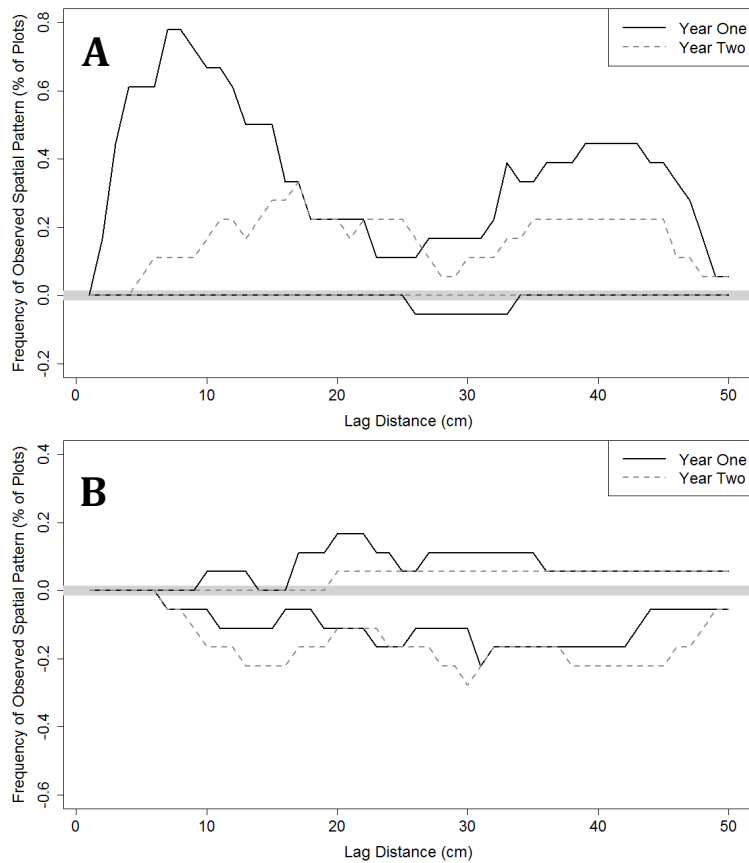
Figure 14 Percentage of plots exhibiting spatial patterns by lag distance in year one and year two for A) seedling bunchgrasses only (Ripley's K1), and B) adult effects on seedlings (Ripley's K1,2). Positive values signify spatial aggregation, negative values signify spatial dispersion for any given lag distance, and values of 0 signify no spatial aggregation or dispersion for a given lag distance. If both positive and negative values exhibited at a particular lag distance, the combination represents a ratio of spatial aggregation to dispersion for that lag distance.

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Neighborhood x Grazing Experiment:

Seedling removal led to earlier within-season senescence for bunchgrass seedlings and reduced seedling and total bunchgrass foliar cover and density and for the duration of the study (Figures 12 & 14). Dormant season defoliation increased flower production but accelerated senescence the year after defoliation (Figures 12 & 13). Growing season defoliation accelerated senescence, decreased flower production, and decreased seedling foliar cover in the same year as applied (Figures 12, 13, & 14A). Seedling mortality differed by year but not by treatment, which we attribute to interannual variability in precipitation.
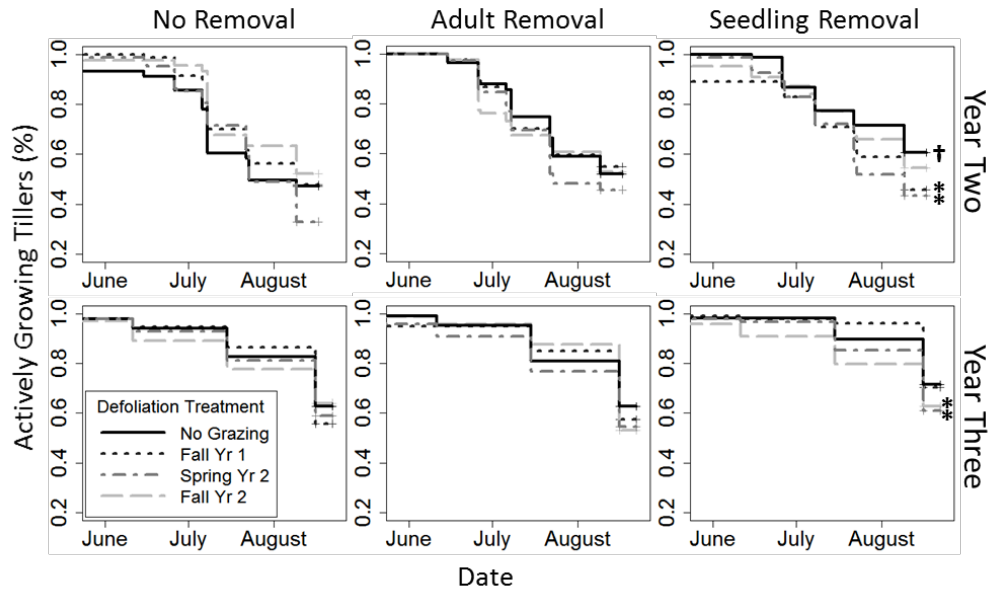
Figure 15 Kaplan-Meier curves showing the percent of seedling tillers actively growing as a function of neighbor removal, defoliation, year, and date. * represent significant differences between defoliation treatments within neighbor treatment and year; † represent significant differences between neighbor treatments within defoliation treatment and year.
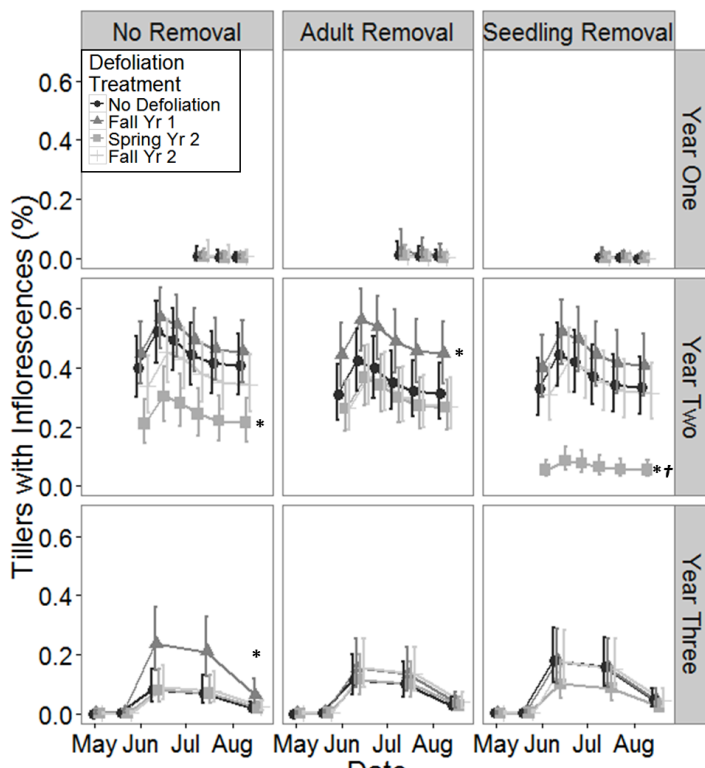
Figure 16 Flower production as a function of neighbor removal treatment, defoliation treatment, year, and date. Error bars represent 95% confidence intervals for each sample date. * represent significant differences between defoliation treatments within neighbor treatment and year; † represent significant differences between neighbor treatments within defoliation treatment and year.
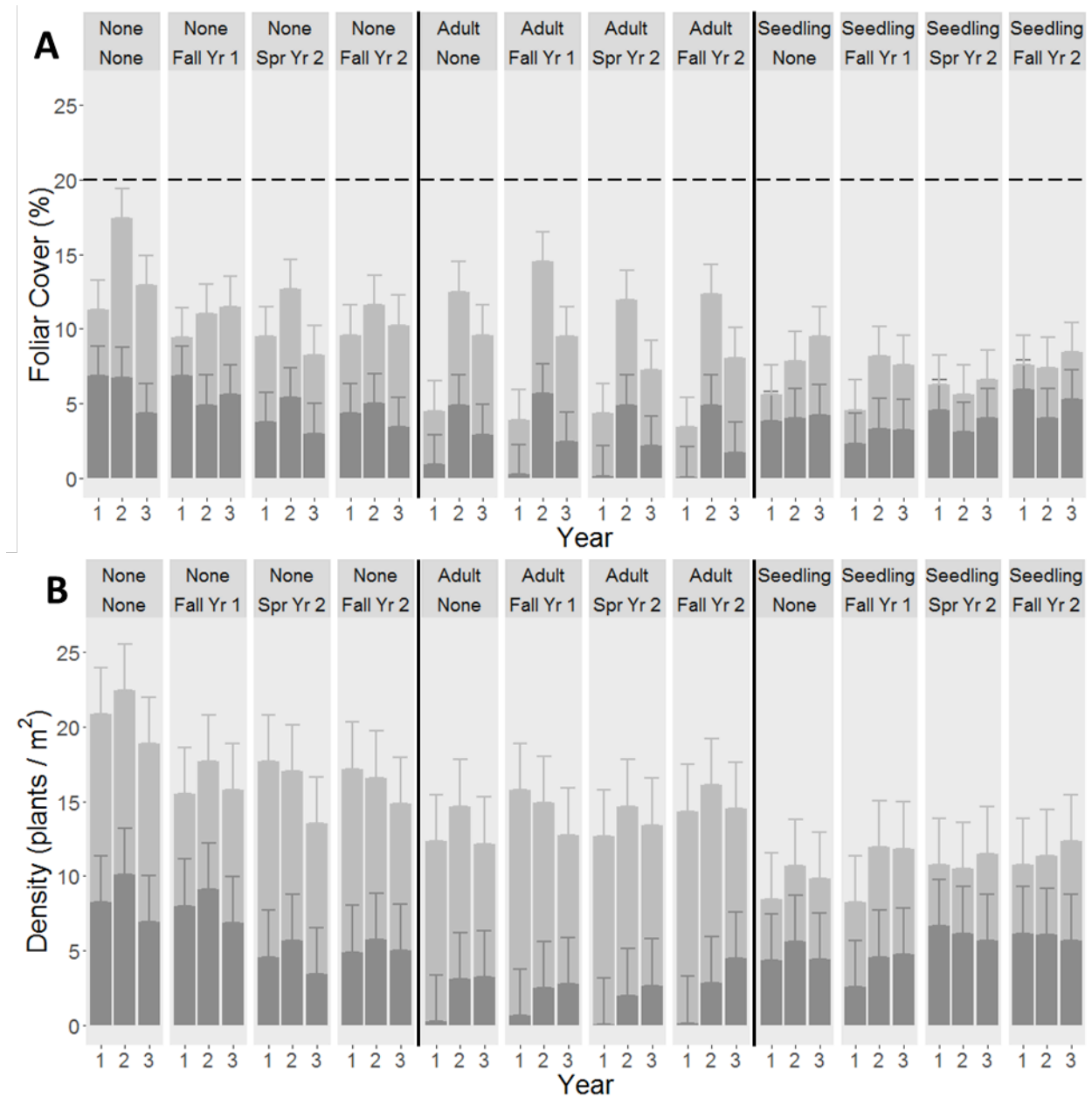
Figure 17 Mean A) percent foliar cover and B) plant density as a function of treatment type, age class, and year. Standard error bars are not shown. Column heading denote neighbor removal treatment (upper row) and defoliation treatment (lower row). Fig. 15 A has a dashed line at 20% foliar cover to denote the current management benchmark for reintroduction of livestock grazing after fire.

3. Burn severity effects on post-fire recovery

Methods

Great Basin

We used Monitoring Trends in Burn Severity (MTBS) fire occurrence data to determine total area burned in the region from 1984-2016 and to identify areas with high frequency of fire occurrence (hot spots) in the Great Basin using the (Getis-Ord Gi*) technique (Getis & Ord 1992). This technique identifies spatial areas with statistically significant high densities of fire occurrence to determine regional hot spots of fire activity. We then used MTBS burn severity data from within all identified hot spots to compare burn severity values (differenced normalized burn ratio, dNBR; relativized differenced normalized burn ratio, RdNBR) across the region's dominant vegetation types using a bootstrapped resampling approach. This analysis allowed us to examine differences in burn severity response across seven dominant vegetation types and two different burn severity indices.

2015 Fires

We also identified five fires that burned in 2015 that were appropriate for researching the effect of burn severity on one year post-fire fuels composition and load: the Saylor, Cold, and 900 Fires in Idaho; the Boulder Fire in Nevada; and the Jaca Fire in Oregon. We downloaded the pre- and post-fire Landsat imagery corresponding to those images from 2014 and within a month after the date of the fire in 2015. We used that imagery to calculate RdNBR (relativized dNBR; Miller and Thode 2007) for the fires. In order to look at recovery along burn severity gradients, we then divided the total range of RdNBR values across all five fires into 10 bins and selected a minimum of 10 sites among fires in each burn severity bin, plus 13 adjacent unburned sites. We sampled fractional cover (green, non-photosynthetic vegetation, rock, soil, and ash) and percent species cover for all sites in summer 2016. We used multi-response permutation procedures (MRPP) to analyze the effect of burn severity on fractional cover: mid/late season green, early season green, nonphotosynthetic vegetation, substrate, char, and ash. We used an NMS to visualize and evaluate variation within and among groups variable.

Results

Great Basin

Eight and one quarter million ha (~15% of region) has burned with areas burning up to seven times in the Great Basin from 1984 to 2016 (Table 2). Of the total area burned, ~77% has burned once while ~23% has burned twice or more. We identified six clusters of high fire occurrence within the ecoregion (Figure 18). Burn severity values differed by pre-fire vegetation type with mean values generally increasing with increasing biomass (Figure 19). However, dNBR and RdNBR exhibited differing responses in magnitude and trend across vegetation types, suggesting that those indices may not be directly comparable and that burn severity should be analyzed within vegetation type rather than across entire fires (Figure 19).

Table 2 Frequency, area burned, and percentage of region burned in the Great Basin from 1984-2016. Data obtained from the Monitoring Trends in Burn Severity (MTBS) database.

# of Times Burned	Area (ha)	Percentage of Region
1	6,330,731	11.4442
2	1,461,415	2.6418
3	345,634	0.6248
4	91,842	0.1660
5	18,504	0.0335
6	4,041	0.0073
*7	493	0.0009
Total	8,252,660	14.9185
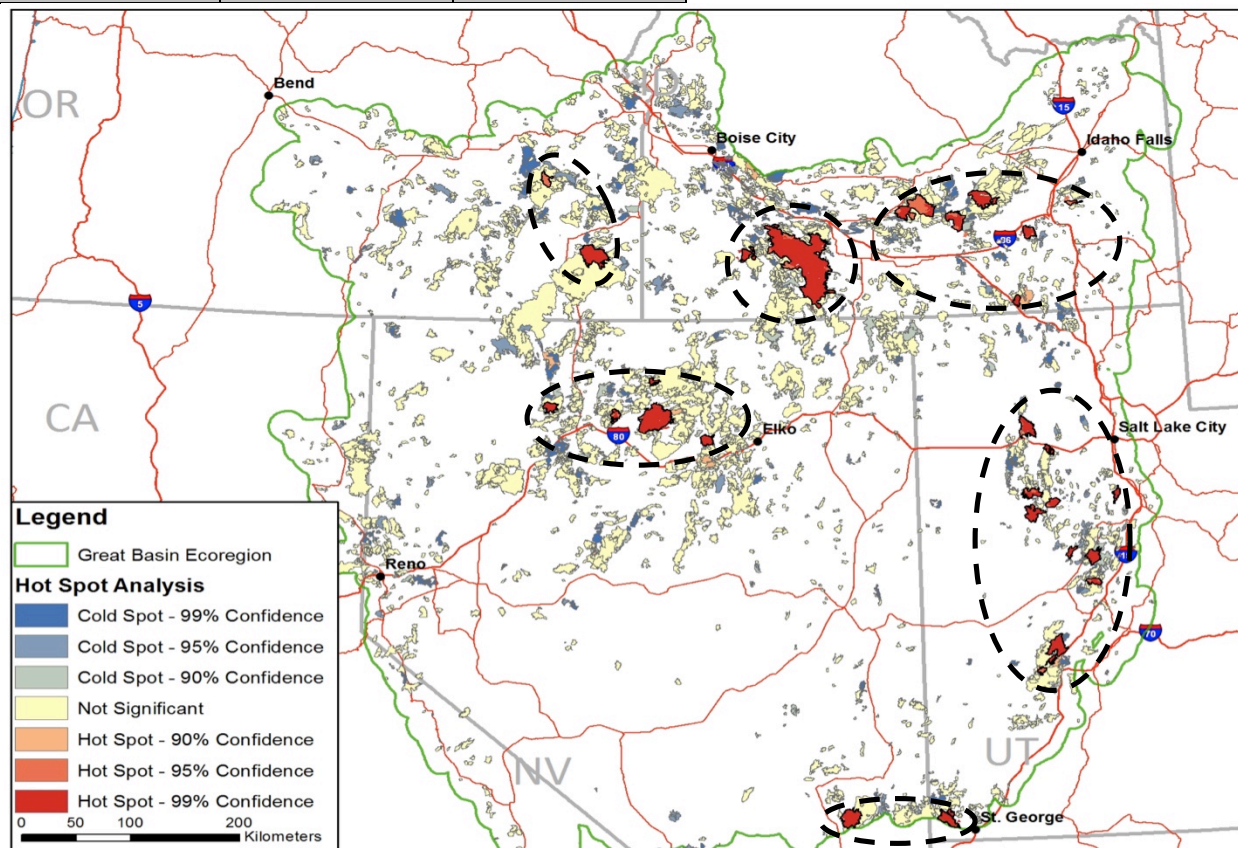
Figure 18 Hot spots of wildfire occurrence in the Great Basin (outlined in black): 1) southeastern Oregon, 2) southwestern Idaho, 3) Southeastern Idaho, 4) central Nevada, 5) western Utah, 6) southeastern Nevada / southwestern Utah. Total area within all hot spots equals 671,791 ha, or 1.2% of the entire region.
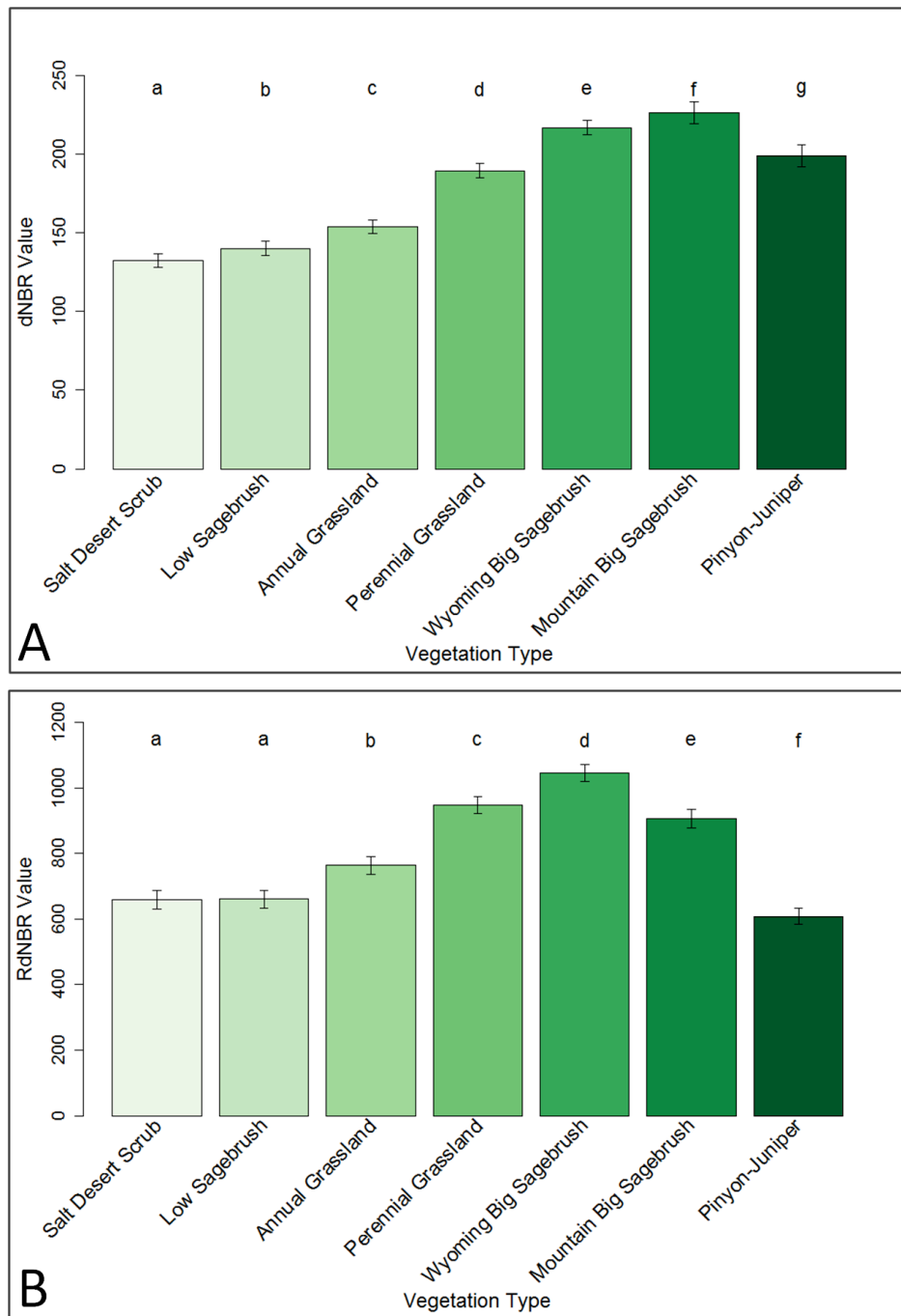
Figure 19 Mean resampled A) dNBR (± SE) and B) RdNBR (± SE) values by pre-fire plant community type. Both dNBR (F = 49065, df=6, P < 0.001) and RdNBR (F = 3981, df=7, P < 0.001) values differed among vegetation types. Vegetation types separated out into seven significant groups for dNBR and six significant groups for RdNBR (Tukey's HSD, p < 0.05). Number of samples represent the frequency of each vegetation type within the hot spot.

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2015 Fires

Each of the fires sampled in 2016 burned in sagebrush steppe, but the pre-fire fuels composition varied from all grass to mixed sagebrush. The primary sagebrush was *Artemisia tridentata wyomingensis* but mixed sagebrush stands included *A. tridentata tridentata*, *Artemisia nova*, or *Artemisia frigida*, depending on the soil and elevation.

The plant communities and fuels composition at sites with the same range of burn severity were more similar to each other than expected by chance, but there was considerable variation. We were unable to distinguish among most severity classes. This suggested burn severity, by itself, was not a good predictor of plant community composition one-year post fire. Plant communities were more similar within fire perimeter irrespective of burn severity. We cannot rule out other site related factors such as differing pre-fire plant communities, different timing of the fire or weather during the fire, differences in isolation from anthropogenic influences, differences in post-fire rehabilitation after the most recent fire, or in fire or post-fire rehabilitation histories.

Cover types across burn severity classes showed distinct trends. One-year post-fire, early season plants (predominately cheatgrass and invasive annual forbs, such as *Sisymbrium altissimum*) increased with burn severity class (Figure 18A), as well as char on non-photosynthetic vegetation cover (Figure 18B). The amount of exposed soil decreased with burn severity class, likely in response to the early season growth (Figure 18C). Non-photosynthetic vegetation cover had a nonlinear response to burn severity, where its cover decreased with low severity fire, increased between RdNBR values of 701-1100, peaked between 1101-1500, then decreased above 1501 RdNBR (Figure 18D).
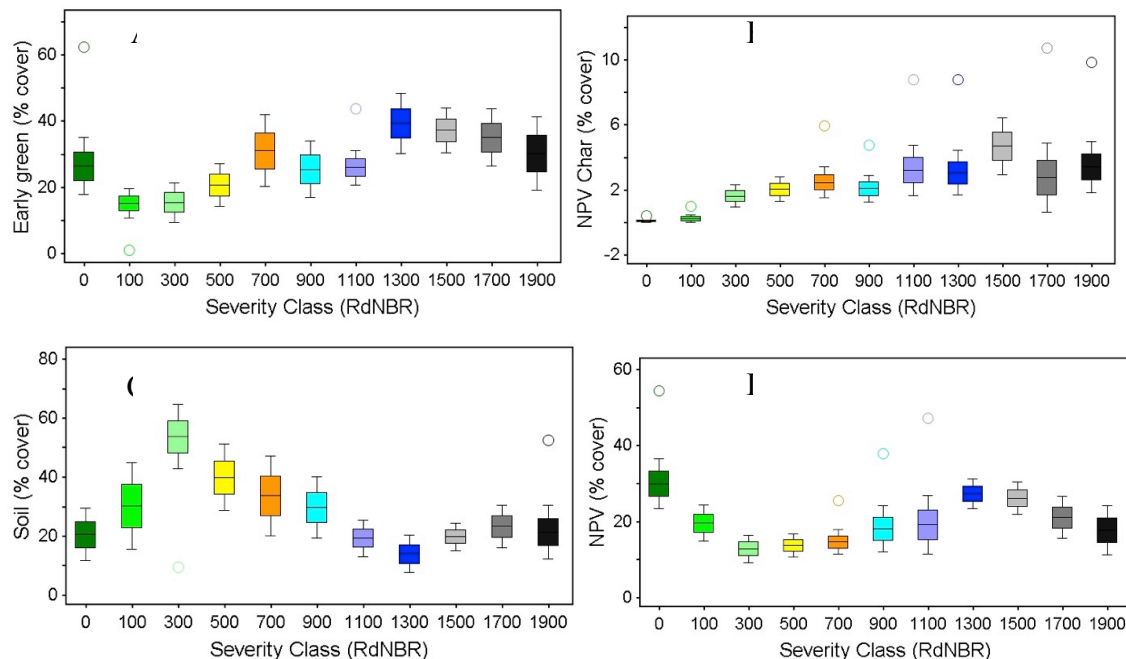

Figure 18 Box plots representing the mean and standard error for cover of early season green plants (A), char on nonphotosynthetic vegetation (B), bare soil (C), and nonphotosynthetic vegetation (D) as a function of binned burn severity class.

Conclusions

Understanding sagebrush steppe ecosystem recovery has been a challenge due to limited information on plant community responses to post-fire fuel treatments (seeding), grazing, and burn severity. Our project provides insights into 1) how aerial and drill seeding affect plant communities, invasion, and fire regimes, 2) how post-fire grazing affects bunchgrass seedling establishment and survival, and 3) the use of MTBS and burn severity indices in rangeland fires and effects on post-fire recovery.

Seeding effects on plant communities by fire and rehabilitation

Sagebrush removal rehabilitation treatments from the mid- to late 20th century began modifying the plant communities, a process exacerbated by subsequent fire and post-fire rehabilitation management decisions. Modern decisions on the type of rehabilitation treatment can shift the trajectory of the dominant vegetation. Drill seeding once and aerially seeding after subsequent fires resulted in eventual mortality of seeded species. Mortality of even fire resilient species means maintaining systems with little *B. tectorum* cover at lower elevations will require drill seeding after every two fires. Multiple drill seeding may not be required at moderate to high elevations where *Artemisia tridentata wyomingensis* exist but should be monitored in the face of climate change for the potential of *B. tectorum* invasions that would require mitigation by drill seeding.

Treatments effects on Bromus tectorum

Across the landscape, *Bromus tectorum* cover was not consistently inhibited by *A. cristatum*. *Poa secunda* cover did inhibit *B. tectorum* but using multiple species of native perennial bunchgrasses more strongly predicted the inhibition of *B. tectorum*. The cover required to maintain low levels of *B. tectorum* cover (<10%) was 40% cover of native perennial bunchgrasses. To inhibit *B. tectorum* after a fire, managers should target use 40% cover of native perennial bunchgrasses as their treatment goal if they wish to minimize fine fuels created by annual grasses. This may require seeding native perennial bunchgrass species greater rates in post-fire seedings than are currently used. Seeding rate experiments should be conducted to ascertain what rate would meet the target goal within 2-3 years, the typical time managers to allow systems to recover after a fire.

Treatments effects on fire regimes

Post-fire rehabilitation had an unexpected effect on fire regimes in our study region. Though fire number and frequency increased with each successive drill or aerial seeding, the increase was far greater when aerial seeding was used. In the study region, aerial seeding was used after a fire for grass, forb, and shrub seed mixes in Wilderness Study Areas (WSA) and in rocky or remote locations, as well as for shrub seed mixes in areas that have a treatment legacy of fire resilient species, such as *Agropyron cristatum, A. fragile*, or *Elymus wawawaiensis*. The WSA in the study area had only burned once during the study period and is unlikely to contribute to the fire frequency seen here. Aerially seeded sites with treatment legacies made up the majority of the sites with multiple fires in the last 20 years. This suggests fuels created by perennial

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bunchgrasses may be contributing to the frequent fires. Perennial bunchgrass fuel loads were greater in aerial seeded sites below 1270 m, which may have contributed to the fire regime seen in those sites.

Post-fire grazing effects on bunchgrasses

Seedling bunchgrasses responded differently to neighbor removal and timing of defoliation. Seedling removal and spring defoliation interacted to produce the most negative effects, suggesting that defoliating when seedling density is low may be unwise. General management recommendations include: 1) promoting bunchgrass seedling growing conditions the first year after fire, 2) avoiding spring defoliation and delaying fall defoliation until at least the second year after fire. If initial seedling density is low, delaying livestock further or implement additional restoration treatments. We acknowledge intrinsic differences across sites, and the need for informed and broad management recommendations; however, a site-specific approach is recommended rather than a one-size-fits-all strategy. Lastly, a conservative approach to reintroducing livestock is appropriate when one is uncertain about possible negative effects on restored species.

Using MTBS to examine fire history and ecosystem recovery

The MTBS dataset proved insight to examining both fire history and ecosystem recovery in the Great Basin. Approximately 15% of the Great Basin has burned since 1984, with 23.2% of that area burning at least twice during that time. Six hot spots of fire activity were identified in the region, denoting areas of highest occurrence and risk for wildfire. These areas may provide managers and researchers focal areas in which to test and implement landscape-level rehabilitation treatments. Factors driving the high frequency of fire in these areas should be investigated further, with a focus on differences in vegetation and number of starts between hot spots. Additionally, we found interesting relationships between burn severity and ecosystem recovery, where annuals tended to increase with severity and soil decreased. We suggest that while burn severity indices can be somewhat misleading when used in rangelands, considering the broad vegetation types helps with interpretation. Additionally, MTBS provides useful information to make management and treatment decisions; however, we emphasize the importance of considering vegetation type when using burn severity data.

Fire in the Great Basin

To conclude, we believe this project has provided a wealth of information about the effects of post-fire seeding, grazing, and burn severity on sagebrush steppe ecosystem recovery in the Great Basin, although there is ample room for continued research. Wildfire burns more acres in the Great Basin than many ecoregions in the US; however, the availability of scientific information about ecosystem consequences is severely lacking. We hope that this information is useful to managers throughout the Great Basin in efforts to manage before, during, and after fire in order to maintain ecosystem function, wildlife habitat, and forage production.

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Appendix B: Completed/Planned Scientific/Technical Publications/ Science Delivery

Publications to Date: (*= graduate student)

Bowman-Prideaux, C.* and B.A. Newingham. *in prep*. The effects of fire history, post-fire rehabilitation, and environmental factors on shrub steppe communities

Bowman-Prideaux, C.* and B.A. Newingham. *in prep*. The effect of species, environment, and post-fire treatments on Bromus tectorum

Bowman-Prideaux, C.* and B.A. Newingham. *in prep*. The Effect of Post-fire Rehabilitation and Climate on Fire Regimes in the Sagebrush Steppe

Gicklhorn, J.M.* and B.A. Newingham. *in review*. Effects of neighboring plants and defoliation on perennial bunchgrass seedlings after fire in Wyoming big sagebrush communities. Restoration Ecology.

Smith, A.M.S., A. Talhelm, C. Kolden, B.A. Newingham, H. Adams, J. Cohen, K. Yedinak, and R. Kremens. 2016. The ability of winter grazing to reduce wildfire size and fire induced plant mortality was not demonstrated: A comment on Davies et al. (2015). International Journal of Wildland Fire. 25:484-488.

Ott, J.E., R.D. Cox, N.L. Shaw, B.A. Newingham, A.C. Ganguli, M. Pellant, B.A. Roundy, and D.L. Eggett. 2016. Post-fire seeding of Great Basin native plants using conventional and minimum-till rangeland drills. Rangeland Ecology and Management. 69:373-385.

Jansen, V.S.*, C.A. Kolden, R.V. Taylor, and B.A. Newingham. 2015. Quantifying livestock effects on bunchgrass vegetation with Landsat ETM+ data across a single growing season. International Journal of Remote Sensing. 34:150-175.

Veblen, K.E., B.A. Newingham, J. Bates, E. LaMalfa*, and J. Gicklhorn*. 2015. Post-fire grazing management in the Great Basin. Great Basin Fire Science Exchange. http://www.gbfiresci.org.

Sparks, A.M*, W.T. Tinkham*, A.M.S. Smith, L. Boschetti, B.A. Newingham, and K.O. Lannom. 2015. An accuracy assessment of the MTBS burned area product for shrub-steppe fires in the northern Great Basin, United States. International Journal of Wildland Fire. 24:70-78.

Presentations to Date: (*= graduate student)

Dencker, C.M., A.G. Smith, and B.A. Newingham. 2018. Wyoming big sagebrush natural recruitment along the fire perimeter. Society for Range Management Annual Meeting, Sparks, NV.

Gicklhorn*, J.M., Newingham, B.A. 2018. Effects of neighboring plants and defoliation on grass seedlings after fire in sagebrush communities. Society for Range Management Annual Meeting, Sparks, NV.

Bowman-Prideaux, C.*, E.K. Strand, and B.A. Newingham. 2017. Working together: Fire and post-fire rehabilitation create homogeneous plant communities. Ecological Society of

America Annual Meeting, Portland, OR.

Pyke, D.A., J.M. Gicklhorn*, B.A. Newingham, M. Trask, and K.E. Veblen. 2017. Tiller demography of two common Great Basin bunchgrasses after fires. Ecological Society of America Annual Meeting, Portland, OR.

Munyer, B.B., C.M. Dencker, J.M. Gicklhorn*, L.D. Derasary, and B.A. Newingham. 2017. Effects of mulch on plant and soil recovery after wildfire in the eastern Great Basin. Great Basin Consortium Meeting. Reno, NV.

Gicklhorn, J.M.*, C.M. Bowman-Prideaux*, E.K. Strand, and B.A. Newingham. 2017. Examining fire occurrence and burn severity in the Great Basin using Monitoring Trends in Burn Severity data. Great Basin Consortium Meeting. Reno, NV.

Gicklhorn, J.M.* and B.A. Newingham. 2017. Grass seedling growth and survival under different post-fire grazing management scenarios. Society for Range Management Annual Meeting, St. George, UT.

Dencker, C.M., J.M. Gicklhorn*, L.D. Derasary, and B.A. Newingham. 2017. Effects of mulch on plant and soil recovery after wildfire in the eastern Great Basin. Society for Range Management Annual Meeting, St. George, UT.

Gicklhorn, J.M.*, C.M. Bowman-Prideaux*, E.K. Strand, and B.A. Newingham. 2016. Examining fire occurrence and burn severity in the Great Basin using Monitoring Trends in Burn Severity data. 3rd Fire Ecology Conference, Tucson, AZ.

Dencker, C., J. Gicklhorn*, L. Derasary, and B.A. Newingham. 2016. Effects of mulch on plant and soil recovery after wildfire in the eastern Great Basin. Sagebrush Ecosystem Conservation Conference. Salt Lake City, UT.

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Dodge, J.*, Bowman-Prideaux, C.*, Strand, E.K., and B.A. Newingham. 2016. Pointing cheatgrass out the door: Analyzing spatial distributions among annual invasives and bunchgrasses. Sagebrush Ecosystem Conservation Conference. Salt Lake City, UT.

Bowman-Prideaux, C. and B.A. Newingham. 2015. Adding Fuel to the Fire: The contribution of perennial bunchgrasses in altering fire regimes in the Great Basin. Association for Fire Ecology Conference. San Antonio, Texas.

Gicklhorn, J.*, K.E. Veblen, B.A. Newingham, J. Bates, and E. La Malfa*. 2015. Effects of post-fire management on plant communities in the Great Basin. Restoring the West conference. Logan, UT.

Graduate Theses

Jeff Gicklhorn, MS in Natural Resources and Environmental Sciences, University of Nevada Reno, October 2017
Chris Bowman-Prideaux, PhD in Natural Resources, University of Idaho, expected December 2018

Course Delivery

Examples and results from this research have been included in two undergraduate and one graduate courses at the University of Idaho. One special topics graduate course was developed and offered specifically for students working on plant community data collected as part of JFSP grants.

Integrating GIS and Field Studies in Rangelands (Senior level undergraduate course REM460)

This course reviews applications of ecological principles in rangeland management; stressing response and behavior of rangeland ecosystems to various kinds and intensity of disturbance and management practices. The course consists of two parts: 1) a five-day field trip in late September, and 2) a series of labs that will review Geographic Information Systems (GIS) applications and utilization of web-based information in rangeland ecosystems observed during the field trip.

In 2016-2018 we included information resulting from JFSP 14-1-01-7 (this grant):
1) Lecture featuring the resilience and resistance concept promoted by the JFSP funded Great Basin Fire Science Exchange.
2) Field trip visits to rangelands where drill seeding of crested wheatgrass had been implemented and higher elevation rangelands without seeding. Discussion of post-fire seeding treatments and resilience and resistance of the sites were evaluated.

Landscape Ecology (Senior level undergraduate course REM429)

Through lecture, discussion, and lab exercises, this course explores the ecological relationships of biotic communities in heterogeneous environments, the implications of pattern over time and space, and the importance of the landscape scale in determining ecosystem diversity and function in forests and rangelands. Natural resource management and conservation issues at the landscape scale are addressed.

In 2016-2018 we included information resulting from JFSP 14-1-01-7 (this grant):
1) An introduction of the Monitoring Trends in Burn Severity (MTBS) program was included in lecture format; and students used MTBS data in a lab exercise where they compared the landscape pattern of MTBS burn severity to the mapped vegetation pattern.
2) Competitive suppression of cheatgrass (*Bromus tectorum*) by native grasses (e.g. squirrel tail and Sandberg bluegrass) and non-native grasses (e.g. crested wheatgrass) and a combination of grass species was presented to students in lecture format and further explored in class discussions. Questions on this topic were included in quizzes and the final exam.

Landscape and Habitat Dynamics (Graduate course REM507)

This course is designed to engage students in using quantitative methods for predicting landscape change and dynamics. Central topics in this course are the concepts of disturbance ecology (fire in particular), potential vegetation, niche modeling, successional change, climate change scenarios, human induced change, and effects of change on species ranges and wildlife

habitat. In the laboratory section of the course we use geospatial analysis tools such as ArcGIS and Spatial Analysis, the Vegetation Dynamics Development Tool, the Maximum Entropy model, and the Wildland Fire Assessment Tool to quantify landscape composition under a variety of modeled management and/or climate scenarios.

The final weeks of the course are dedicated to development, analysis, and reporting of an independent research project on a topic of particular interest to the student. Publication of the final project is encouraged. Two of the graduate students in the course were funded by JFSP grants 14-1-01-7 (this grant) and 14-1-02-27. One of the students, Chris Bowman (funded by this project), focused research on evaluating the effectiveness of drill seeding and aerial seeding in reducing the fire frequency in sagebrush steppe ecosystems in southern Idaho. The research was presented to the class and the paper started in this course will result in a dissertation chapter and a peer-reviewed publication.

Plant Community Analysis (Graduate course REM504)

Plant Community Analysis was developed and offered as a special topics course in the fall of 2016 to support students funded by JFSP grants 14-1-01-7 (this grant) and 14-1-02-27. The directed study reviewed the definitions of a plant community and ecological concepts including environmental niche, secondary succession, disturbance regime characteristics, species diversity, and fire response. Definitions of burn severity in the field and via remote sensing were reviewed. We used the PC-ORD software for multivariate statistical analysis of plant community data. Methods included gradient analysis (ordination), classification, group testing, and indicator species analysis. Students were assessed by contribution to discussion, four oral presentations, and a final project paper.

Objectives
1) Gain understanding of drivers of plant community composition including environmental site potential, succession, disturbance, and competition.
2) Compile a plant community dataset that can be analyzed using multivariate analysis in the PC-ORD software.
3) Document fire response characteristics of the most frequent plants within the dataset.
4) Write a publication quality paper about the plant community and analysis

Learning outcomes
1) Learn and integrate - Understand the structure and function of plant communities and their response to wildfire.
2) Think and create – Use multivariate statistical analysis strategies, critically analyze plant community data and display relationships to communicate results.
3) Communicate – Be able to articulate, through verbal and written communication, plant community characteristics, ecological relationships, and statistical analysis techniques.
4) Clarify purpose and perspective – Explore the purpose of gradient analysis and how it can assist in understanding short- and long-term implications of environmental site characteristics and disturbance on plant community composition.
5) Practice citizenship – Contribute to course discussion, provide constructive feedback to course participants, and contribute to the scientific community via publications.