FINAL REPORT

Do perennial bunchgrasses competitively exclude *Bromus tectorum* in post-fire rehabilitation across spatial scales?

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Keywords

Bromus tectorum, *Poa secunda*, *Agropyron cristatum*, *Elymus elymoides*, *Achnatherum thurberianum*, Nonparametric Multiplicative Regression, Invasions, Post-fire Rehabilitation, Fire History

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Abstract

Globally, wildfire size and frequency has increased in the last thirty years across numerous ecosystems. Models predict that trend to continue with increases in temperature and shifts in seasonal precipitation caused by climate change. In the western United States, these trends are exacerbated by invasive annual grasses that create self-perpetuating fire regimes with frequent, large fires. The annual grass, *Bromus tectorum* (cheatgrass), has radically altered fire regimes in the Great Basin and contribute to the degradation and loss of sagebrush habitat. Successful post-fire establishment of sagebrush steppe vegetation and rangeland health will require controlling the cover and density of *B. tectorum* in the species extant range through post-fire rehabilitation. Attempts to synthesize the effects of post-fire rehabilitation in rangelands are hampered by the lack of research in these systems at landscape-scales.

Research conducted in small field plots and common gardens suggest some perennial bunchgrasses may limit the growth, cover, or reproduction of *B. tectorum*, but the scalability of small-scale research across landscapes and post-fire treatment histories is uncertain. Three perennial bunchgrasses commonly used in post-fire rehabilitation—*Agropyron cristatum* (crested wheatgrass), *Elymus elymoides* (bottlebrush squirreltail*)*, *Poa secunda* (Sandberg bluegrass)—have been shown to reduce the productivity, growth, and/or reproduction of *B. tectorum* at the common garden or plot level, but their effectiveness over large scales is unclear.

Data on plant cover and density was collected on 67 sites in a 209,000 ha study area that varied in fire and post-fire rehabilitation history along gradients in elevation, soil texture, and precipitation. Multiple linear regression indicated significant inverse relationships between *B. tectorum* and both *P. secunda* and *A. cristatum*, but *P. secunda* had suppressed *B. tectorum* cover and density better than *A. cristatum*. A nonparametric multiple regression analyzing the effect of 86 abiotic and biotic independent variables indicated that elevation, mid to late season native perennial bunchgrasses, and the number of post-fire rehabilitation treatments (for *B. tectorum* cover) or time since most recent rehabilitation (for *B. tectorum* density) explained the most variation in *Bromus tectorum* suppression across the landscape.

Objectives

We had two objectives for this project. First, we wanted to determine if *P. secunda*, *E. elymoides*, and *A. cristatum* would inhibit *B. tectorum* cover and density. Second, we wanted to determine if small scale results were scalable to the landscape scale at sites that differed in abiotic conditions and post-fire management actions. We had two hypotheses: 1) Perennial bunch grasses would decrease *B. tectorum* cover and density; 2) This result would be the same at all our sites across our study area.

Background

Globally, wildfire size and frequency has increased in the last thirty years across numerous ecosystems (Goetz et al. 2007). Models predict that trend to continue due to increases in temperature and shifts in seasonal precipitation caused by climate change (Liu et al. 2010). In the western United States, these trends are exacerbated by invasive annual grasses that alter fire regimes resulting in frequent, large fires (Brooks et al. 2004). *Bromus tectorum* reduces fire return intervals, broadens fire extent, and increases the likelihood of a fire spreading into adjacent, non-invaded vegetation (Balch et al. 2013, Davies and Nafus 2013). Models based on future climate suggest the range of *B. tectorum* will expand northward and upward in elevation (Bradley 2009, 2010).

Bromus tectorum alters ecosystem structure and function. Early phenology allows *B. tectorum* to use resources while many native perennial plants are still dormant (Mack and Pyke 1983). Once established, *B. tectorum* promotes its invasion by facilitating the spread of root pathogen and altering nutrient cycles (Melgoza et al. 1990, Ogle et al. 2003, Sperry et al. 2006, Beckstead et al. 2010). Fire and altered resources reduce native grass cover, while repeated fire eliminates *Artemisia tridentata* (big sagebrush) from the landscape (West and Hassan 1985, Davies et al. 2009). These changes in native vegetation result in habitat loss for sagebrush obligates and other wildlife (Welch and Criddle 2003, Coates and Delehanty 2010). Managing cheatgrass cover and increasing ecosystem resistance to invasion is therefore an important goal of post-fire rehabilitation in the Great Basin (Baker 2006).

Several small-scale studies have suggested there are species of perennial bunchgrasses that may help ecosystem resistance to invasion by *B. tectorum*. *Agropyron cristatum* (crested wheatgrass) and *A. desertorum* are Eurasian bunchgrasses that suppress the growth and reproduction of *B. tectorum* and are resilient to fire (Svejcar 1990). The native bunchgrass, *Elymus elymoides* (bottlebrush squirreltail), inhibits *B. tectorum*, facilitates sagebrush recruitment, and is somewhat resistant to fire (Wright and Klemmedson 1965, West and Hassan 1985, Arredondo et al. 1998, Booth et al. 2003). *Poa secunda* (Sandberg's bluegrass) is an early season, native bunchgrass that can suppress *B. tectorum* productivity in the spring and may evolve earlier phenology in response to invasion (Link et al. 1990, Goergen et al. 2011). Fire reduced *P. secunda* biomass, but had no effect on plant density or productivity (West and Hassan 1985, Davies et al. 2009).

Post-fire Emergency Stabilization and Rehabilitation (ESR) plans often include seeding to reduce fine fuels caused by exotic annual plants. The most common application methods are drill and aerial seeding or a combination of the two. *Elymus elymoides, P. secunda*, and *A. cristatum* are added to post-fire rangeland seed mixes, but only limited published research exists on the effectiveness of such post-fire rehabilitation on *B. tectorum* cover or biomass (Knutson et al. 2014, Taylor et al. 2014). We will examine the relationship between bunchgrasses species and *B. tectorum* to determine whether one or more species may reduce or exclude *B. tectorum* from sites. Understanding the dynamics of *B. tectorum* establishment with each bunchgrass alone or in tandem will potentially inform the seed selection and relative proportions for future rehabilitation efforts.

Materials and Methods

Study Area

Research was conducted at 68 sites across 209,000 ha of historically Wyoming sagebrush steppe in southern Idaho (Figure 1). The most common plants were *Poa secunda* (Sandberg's bluegrass), *Agropyron cristatum* (crested wheatgrass) and *Bromus tectorum* (cheatgrass, downy brome). *Artemisia tridentata wyomingensis* was found on unburned sites and on a few sites that burned only once. A complete species list and the number of sites each species was found is included in Appendix D. Parameter-elevation Relationships on Independent Slopes Mode (PRISM) modeled climate data indicated precipitation varied from 220-364 mm among sites (Climate Group 2014); elevation ranges from 780-1790 m (USGS 2012). The first recorded fire for these sites ranged from 1958 to 2012 with 32 sites burning for the first time between 1970-1989 (BLM 2013). 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. All sites were grazed, though sites with fires, but sites that burn ≤ 2 years prior to research were not grazed during data collection.

Sampling Design

We sampled plant canopy cover and density by species at each site in 2014 and 2015. Each site was 180 m^2 with three parallel 30 m transects separated by 30 m. Plant cover was collected along each transect using line-point intercept at 10 cm intervals with a random starting point at each transect. We estimated plant density using five-1 m^2 quadrats spaced 6 m apart along each transect (total of 15 quadrats per site). The sites represented a combination of rehabilitation treatments—drill seeded, aerially seeded or untreated—(Pilliod and Welty 2013, NOC 2014) and fire history—unburned and 1, 2,3, or 6 fires (BLM 2013). Analyses showed there was no difference among years so data were pooled across 2014 and 2015.

Analysis

The effect of *A. cristatum*, *P. secunda*, and *E. elymoides* on *B. tectorum* was analyzed in two ways. We used linear regressions using the cover of each bunchgrass species as the independent variable and cover of *B. tectorum* as the dependent variable. We then ran a regression of the summed cover of the three perennial bunchgrasses and to determine if having all three bunchgrasses was more effective at inhibiting *B. tectorum*. The regressions did not take into consideration differences that may have risen from interactions with fire or rehabilitation history. This analysis yielded an analysis of the overall effect of the perennial bunchgrasses in question on *B. tectorum*. Since some sites were never seeded with *A. cristatum*, sites lacking in that species were eliminated from the analysis, resulting in an analysis using 49 sites. Likewise, sites without *E. elymoides* were dropped from the analysis of the effect of *E. elymoides* on *B. tectorum*, resulting in an analysis with 32 sites.

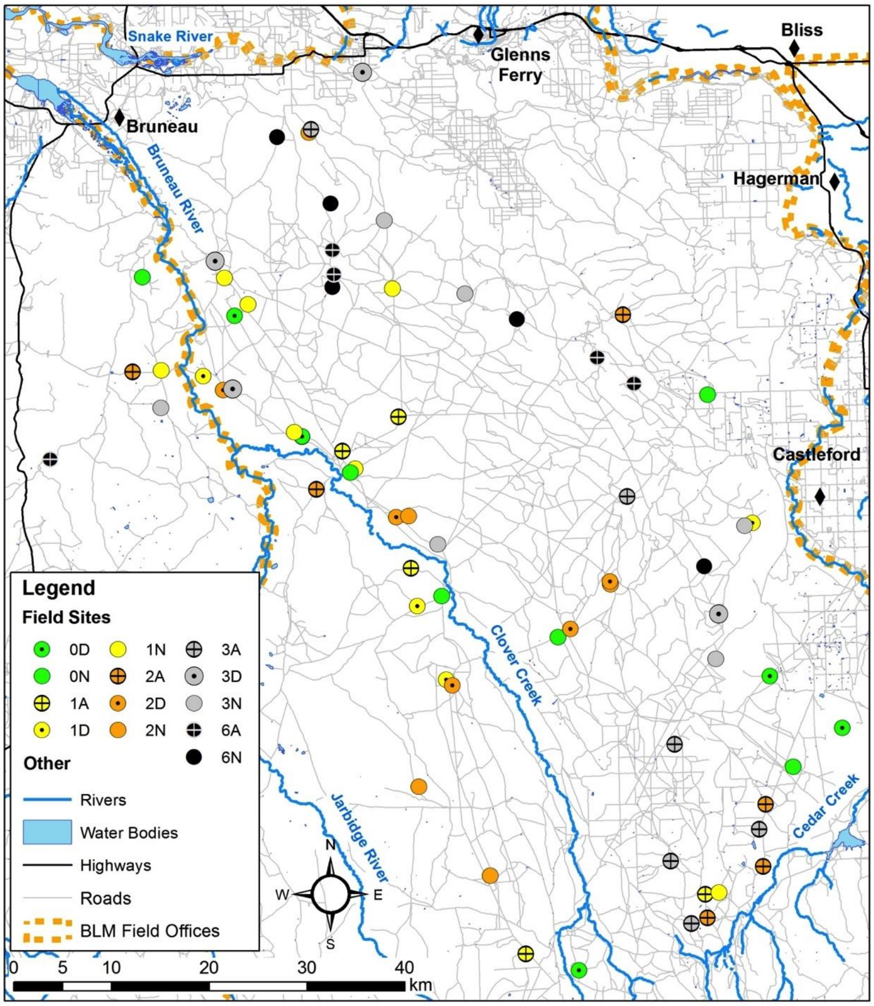

Figure 1 Study sites selected for this project organized by number of fires since 1958 (color) and treatment after most recent fire (symbol). Sites with six fires concentrated in the north, sites only burned once concentrated in the west, and unburned sites are along the periphery. N = not seeded, D = drill seeded, A = aerially seeded.

We used a Nonparametric Multiplicative Regression (NPMR) in HyperNiche 2.3 (McCune and Mefford 2009) to determine which variables most influenced *B. tectorum* cover and density. The advantage of the NPMR is that it determines how explanatory variables interact in nonlinear and multiplicative ways to alter the dependent variable. We conducted a free search using a quantitative local mean Gaussian weighting model. We controlled for overfitting through minimum average neighborhood size, minimum data-to-predictor ratio, and an improvement in fit criteria. Fit was assessed using cross-validated R^2 (xR^2). For each analysis, we identified the best fitting model as that which resulted in a 5% increase in fit over the next-best model with one less predictor variable. Since xR^2 are calculated using a ‘‘leave-one-out’’ cross validation, the training data error rate is expected to approximate that of validation data sets. Consequently, we did not withhold data for validation purposes. Instead, we used full datasets to maximize our ability to model relationships across large geographic and environmental gradients. Bootstrap resampling (each dataset resampled with replacement 1000 times to generate 1000 new datasets, each with n - 1 plots) was used to quantify the stability of models against the inclusion of particular plots in a given analysis by providing an average fit (±SE) between the final model and 100 resampled datasets.

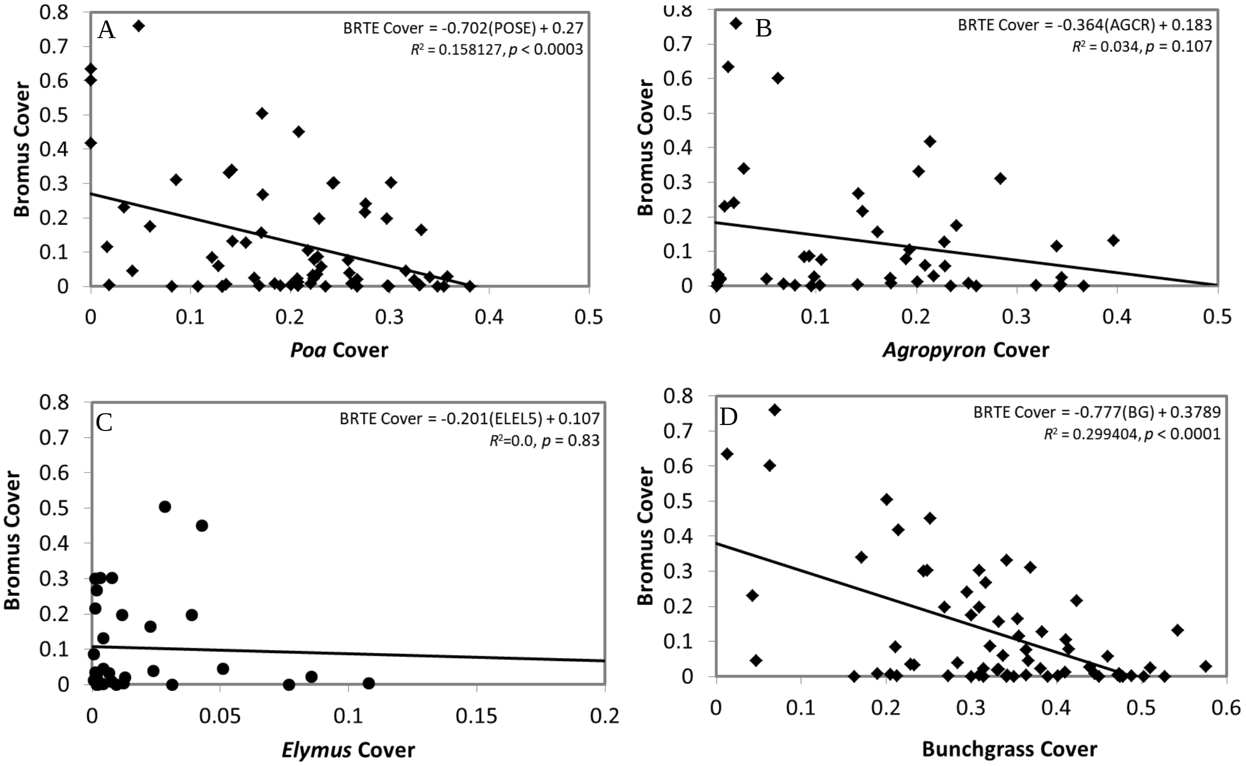

Figure 2 Scatter plots showing linear regression plotted for the effect of the proportion of cover for *P. secunda* (A), *A. cristatum* (B), *E. elymoides* (C), and the cover of all three species on *B. tectorum* cover.

In addition, we report the average neighborhood size (the average number of sample units contributing to the estimate of occupancy at each point on the modeled surface). Tolerance values are also given for each quantitative predictor variable. High tolerance values, relative to the range of the predictor, indicate that data points with a greater distance (in predictor space) from the point targeted for estimation contribute to the estimate of the response variable's value at the target point. Sensitivity, which generally ranges from 0 to 1, indicates the relative importance of each quantitative predictor in the model. A sensitivity of 1 indicates that, on average, changing the value of a predictor by ±5% of its range results in a 5% change in the estimate of the response variable, whereas a sensitivity of 0 indicates that changing the value of the predictor has no effect on the response variable.

We used 83 predictor variables including fire and treatment history; monthly, seasonal, and annual climatic variables; elevation, and the percent cover and density of all the plants sampled at the sites. A complete list of abiotic variables used in the predictor matrix is in Appendix D. We conducted four NPMR analyses. *Bromus tectorum* cover and density was evaluated with site and species data first. Then we created summed cover and density variables for native perennial bunchgrass that included all native perennial bunchgrasses except *P. secunda*. *Poa secunda* was not included because it is smaller and has a different phenology from most native perennial bunchgrasses.

Results

Across our study area, *P. secunda* cover inhibited *B. tectorum* cover (Figure 2A). Both *A. cristatum* and *E. elymoides* cover did had an inverse relationship with *B. tectorum* cover, however, the slopes did not differ significantly from zero (Figure 2B, C). Pooling *P. secunda*, *E. elymoides*, and *Agropyron cristatum* into a single perennial bunchgrass variable resulted in greater, inverse slope and explained more of the variation than *P. secunda* alone (Figure 2D).

Table 1 NPMR results for BRTE cover and density with and without native perennial bunchgrass (NPBG) cover and density pooled. The variables that composed the best-fit models include elevation (Elev), *E. elymoides* cover (ELEL5_C), number of rehabilitation treatments (Rehab), *Achnatherum thurberianum* cover (ACTH7_C), and time since last post-fire rehabilitations (tLT).

Response Variable	**xR^2**	**Bootstrap xR^2**	**Avg. Size**	**Predictor**	**Sensitivity**	**Tolerance**	
Bromus Cover	0.626	0.74 (± 0.009)	4	Elev	0.791	50.59	(5%)
				ELEL5_C	0.0915	0.0162	(15%)
				Rehab (n)	0.081	1.8	(30%)
Bromus Density	0.638	0.69 (± 0 .114)	4.9	Elev	0.647	50.59	(5%)
				ACTH7_C	0.231	0.0036	(5%)
				tLT	0.031	35.4	(60%)
Bromus Cover NPBG	0.624	0.73 (± 0.025)	4.2	Elev	0.809	50.59	(5%)
				NPBG_C	0.097	0.0659	(15%)
				tLT	0.041	38.35	(65%)
Bromus Density NPBG	0.638	0.69 (±0 .114)	4.9	Elev	0.647	50.59	(5%)
				ACTH7_C	0.231	0.0036	(5%)
				tLT	0.031	35.4	(60%)

The best fit NPMR three variable models explained much of the variation in *B. tectorum* cover and density (

Table 1). All the variables had nonlinear effects on *B. tectorum* cover and density. Elevation (Elev) was consistently important with a 51 m change in elevation resulting in a 3.9% change in *B. tectorum* cover and 3.2% change in density. *Bromus tectorum* cover and density decreased rapidly with an increase in elevation between 750 m and 1000 m then increased with elevation between 1000 m and 1300 m before resuming an inverse relationship with elevation above 1300 m (Figure 3). *Bromus* cover increased with *E. elymoides* cover (ELEL5_C) until *E.*

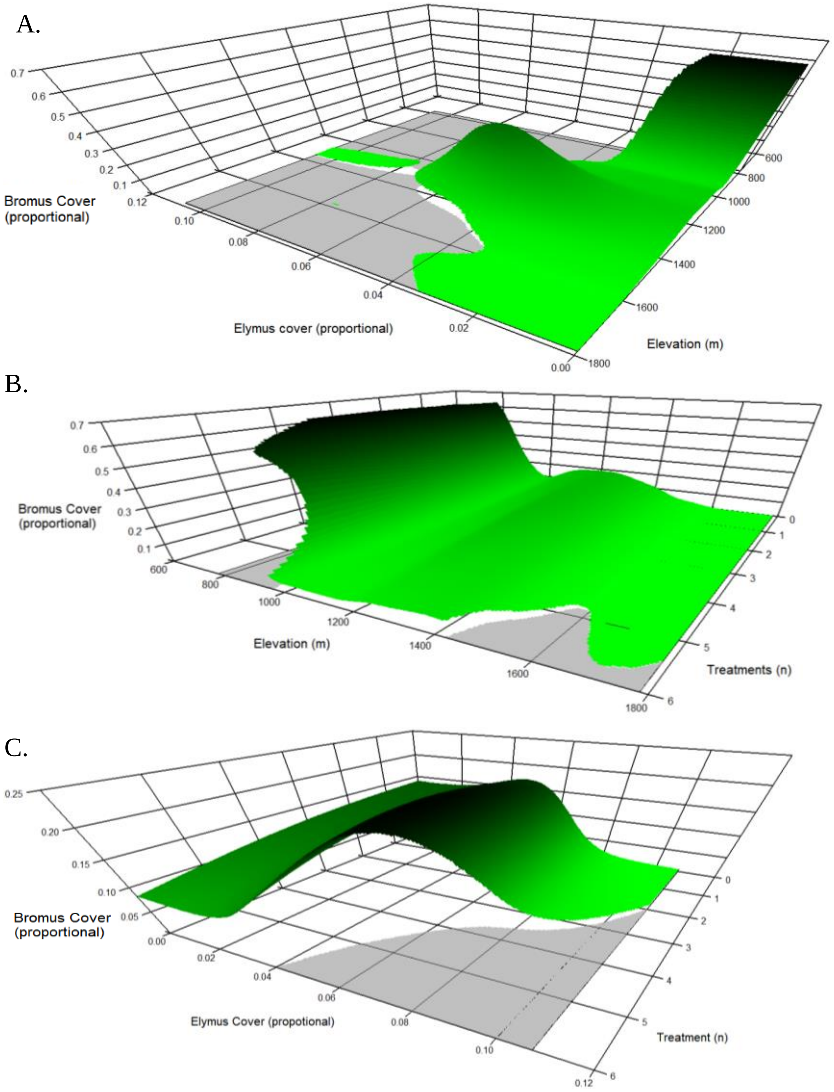

Figure 3 NPMR modeled relationship for *Bromus tectorum* cover when NPBG cover and density was not included in the predictor matrix for: A) Elevation and *Elymus elymoides*, B) Elevation and vegetation treatments, and C) Elymus cover and treatments. Cover for *Bromus* and Elymus cover is proportional rather than percent cover. 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.

elymoides cover reach 4-5% at which point *B. tectorum* cover decreased to nearly zero as *E. elymoides* cover approached 12% cover (Figure 3). At low elevations, there was a stronger inverse relationship between *B. tectorum* cover and elevation on sites with 0-1 post-fire rehabilitation seedings (Figure 3). At elevations above 1100 m *B. tectorum* cover decreased with an increase in more post-fire rehabilitation. When *E. elymoides* cover was below 3%, *B. tectorum* cover decreased with additional rehabilitation efforts (Figure 3).

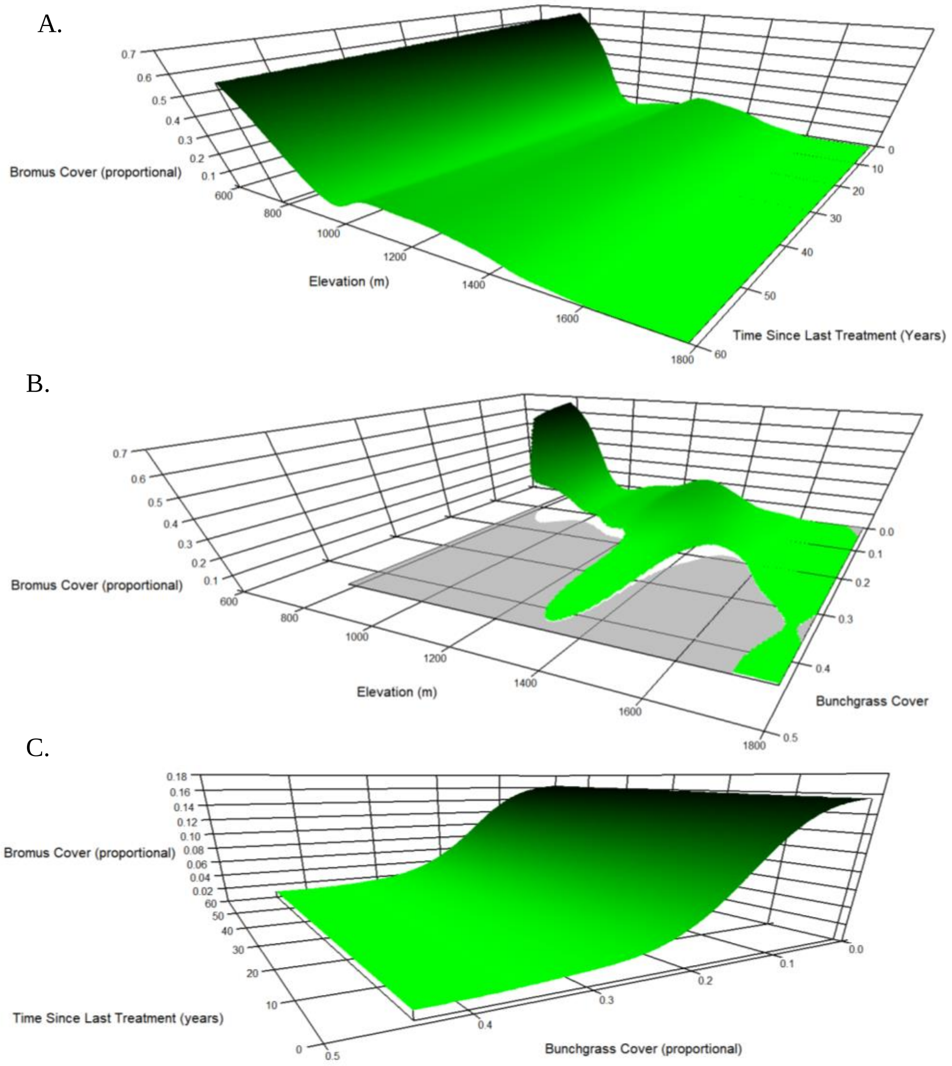

Figure 4 NPMR modeled relationship for *Bromus tectorum* cover when NPBG cover and density was included in the predictor matrix for: A) Elevation and time since last treatment, B) Elevation and bunchgrass cover, and C) bunchgrass cover and time since last treatments. Cover for *Bromus* and bunchgrass cover is proportion of cover rather than percent cover. 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.

The best fit model for *B. tectorum* changed when native perennial bunchgrass cover and density was added to the explanatory matrix (

Table 1). The model with time since the most recent treatment (tLT), elevation, and native perennial bunchgrass cover (NPBG_C) explained the most variation. Between 1000m and 1200mm *B. tectorum* cover increased with time since last treatment, but *B. tectorum* cover was unaffected by time above 1200m (Figure 4). Above an elevation of 1400 m, *B. tectorum* cover was unaffected by native perennial bunchgrass cover until bunchgrass cover was approximately 20% (Figure 4). Time since last treatment did not affect the inhibition of *B. tectorum* cover by native perennial bunchgrass.

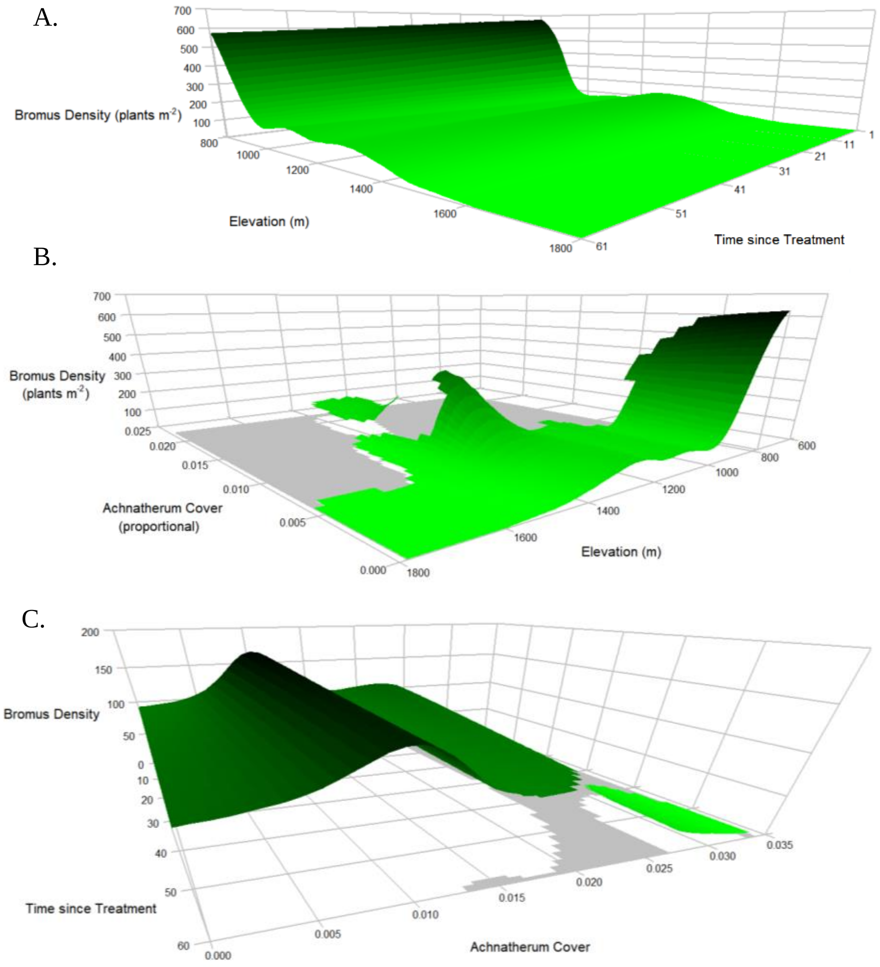

Figure 5 NPMR modeled relationship for *Bromus tectorum* cover when NPBG cover and density was not included in the predictor matrix for: A) Elevation and time since last treated (in years), B) Elevation and *A. thurberianum* cover, and C) *A. thurberianum* cover and time since last treatment. Cover for *Bromus* and Elymus cover is proportional rather than percent cover.

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.

The best fit model for *B. tectorum* density included time since last rehabilitation treatment, elevation (Elev), and *A Achnatherum thurberianum* cover (ACTH7_C,

Table 1). At elevations below 1100 m, *B. tectorum* density increased slightly with time since most recent vegetation or rehabilitation treatment (Figure 5). Between 1100 m and 1400 m, *B. tectorum* density decreased with time since most recent treatment. Above 1400 m, time since treatment had little effect on *B. tectorum* density. *Achnatherum thurberianum* was found in an elevational band between 1100 m and 1600 m. *Bromus* density increased with *A. thurberianum* cover (ACTH7_C) until *A. thurberianum* reached 1% cover (Figure 5). Above 1% cover of *A. thurberianum B. tectorum* density decreased rapidly. Time since last treatment did not alter the effect of *A. thurberianum* cover on *B. tectorum* cover. Adding native perennial bunchgrass cover and density to the explanatory variable matrix did not alter the best fit model (

Table 1).

Discussion

The objectives of this project was to evaluate the 1) effectiveness of *P. secunda*, *E. elymoides*, and *Agropyron cristatum* at inhibiting *B. tectorum* cover and density across a landscape that 2) varied in fire and post-fire rehabilitation treatment history along gradients in elevation and climate. The linear regression showed *P. secunda* inhibited *B. tectorum* cover irrespective of the variation in treatment or fire history. *Agropyron cristatum* and *E. elymoides* did not inhibit *B. tectorum* at the landscape scale. *Elymus elymoides* had a non-linear effect on *B. tectorum* with inhibition once *E. elymoides* reached 5% cover. The NPMR also indicated the number of treatments, time since last treatment and elevation were important determinants of *B. tectorum* cover and density.

We found a significant but weak inverse relationship between *P. secunda* and *B. tectorum* (Figure 2A). Several other studies have explicitly or implicitly shown an inverse relationship between *B. tectorum* and *P. secunda*. Native perennial herbaceous cover negatively impacted *B. tectorum* cover six years post-fire in a *Pinus monophylla-Juniperus osteosperma-A. tridentata vaseyana* community (Condon et al. 2011). In an A. tridentata wyomingensis community, native perennial bunchgrass cover was inversely related to *B. tectorum* (Davies et al. 2012). Goergen et al. (2011) found *P. secunda* inhibited *B. tectorum* biomass, but only *P. secunda* and one population of *E. multisetus* flowered in the first year of a greenhouse study. One reason for *P. secunda* effect on *B. tectorum* at these sites may be that *P. secunda* has shifted its phenology to precede *B. tectorum* as it has in other studies (Link et al. 1990, Goergen et al. 2011). Greening and dropping seed before *B. tectorum* would give *P. secunda* an advantage in access to resources. Since *P. secunda* and *B. tectorum* have similar phenologies and physiological responses to limited resources (Phillips and Leger 2015), it makes sense that *P. secunda* would inhibit *B. tectorum*.

When we included *Agropyron cristatum*, *E. elymoides*, *Poa secunda* in a linear regression the relationship was stronger, and the inhibition of *B. tectorum* cover was greater. This indicates having a greater diversity of perennial bunchgrasses may be more effective at suppressing *B. tectorum* cover. In *A. tridentata wyomingensis* communities, a reduction in cover of four native perennial bunchgrass species was concurrent with an increase in *B. tectorum* cover over three years (West and Hassan 1985). *Poa secunda sandbergii* and other native perennial bunchgrasses increased one year post-fire while *B. tectorum* cover decreased (Akinsoji 1988). There was an inverse relationship between native perennial bunchgrass cover and *B. tectorum* (Davies et al. 2012). Goergen et al. (2011) found *P. secunda*, *Elymus multisetus*, *Achnatherum hymenoides*, and *Hesperostipa comata* suppressed *B. tectorum* biomass, but only *P. secunda* and one population of *E. multisetus* flowered in the first year of a greenhouse study. At their Bedell Flats site in Nevada, where three native perennial bunchgrass were found, native grass clones from invaded sites significantly inhibited *B. tectorum* biomass better than plants from uninvaded sites (Goergen et al. 2011). Mangla et al. (2011)found that *P. spicata* suppressed *B. tectorum* biomass better than *P. secunda*. *Poa secunda* cover expanded after *B. tectorum* removal in former *A. tridentata wyomingensis* steppe (Davies et al. 2012).

It was surprising that the linear regression did not detect a significant inverse relationship between *E. elymoides* and *B. tectorum*. Arredondo et al. (1998) noted *E. elymoides* could invade *B. tectorum* and *Taeniatherum caput-medusae* (L.) Nevski stands, attributing the fact to similarities in morphology. Booth et al. (2003) noted that *E. elymoides B. tectorum* cover suppressed more than would be expected based on its cover and suggested that *E. elymoides* was "maintaining zones free of *B. tectorum*." In an examination of abandoned agricultural fields, *B. tectorum* did not dominate some old fields at sites where *E. elymoides* was present (Morris et al. 2011). Those studies suggest we should have seen an inverse relationship with *B. tectorum* cover. Though the presence of *E. elymoides* appears to inhibit *B. tectorum* in sagebrush steppe, it is worth noting that *B. tectorum* cover and density were unaffected by *E. elymoides* in ponderosa pine forests (Brooks et al. 2010).

Though we did not detect a linear relationship between *B. tectorum* and *E. elymoides*, the NPMR did detect a Gaussian relationship. *Bromus tectorum* cover increased with *E. elymoides* until *E. elymoides* cover reach 5% then *B. tectorum* declined rapidly. In an examination of abandon agricultural fields, *B. tectorum* did not dominate some old fields where *E. elymoides* was present and *P. secunda* cover was ≥4% (Morris et al. 2011). Ferguson et al. (2015) found *E. elymoides* was not a good competitor, rather the species is good at dispersing and establishing in *B. tectorum* dominated communities. It may take time for decades *E. elymoides* to dominate and many of our sites have burned within the last 2-15 years. Perhaps there was not enough time for a linear relationship to develop.

Bromus tectorum cover and density are linked to certain anthropogenic features in the landscape. Bradley and Mustard (2006) showed *B. tectorum* more likely near agriculture, roads, and transmission lines. At our study sites, the greatest source of disturbance from those features noted by Bradley and Mustard were found at our lowest elevation sites. The NPMR models show a steep decrease in *B. tectorum* cover and density between 700 m and 1000 m. This may be an artifact of the proximity of low elevation to small towns and agriculture. Scientists and land managers have long acknowledge *B. tectorum*'s preference for lower elevations in the Great

Basin (Beatley 1966). Bradley and Mustard (2006) found *B. tectorum* present at elevations from 1100 m - 2000 m, but was most probable at sites around 1400 m. The probability of finding *B. tectorum* decreased above 1450 m. The same was true in the present study where the NPMR modeled *B. tectorum* cover and density increased from 1000 m to 1400 m, then decreased again.

Bromus tectorum cover and density was at or near zero at sites above 1700. That suggests high elevation communities in southern Idaho are more resistant to *B. tectorum*. The decrease in *B. tectorum* cover and density with elevation is similar to the work of other researchers (Beatley 1966, Bradley and Mustard 2006, Chambers et al. 2007, Chambers et al. 2014), however, we are to our knowledge the first to show the decrease in *B. tectorum* cover decreases above 1400 m is true regardless of a mosaic of sites that varied in fire and rehabilitation treatment histories. This doesn’t mean that high elevation sites will remain immune to *B. tectorum* invasions. Griffith and Loik (2010) saw a doubling of *B. tectorum* cover at 2150 m. Climate change could shift the preferred thermal and ecohydrological niche up elevational gradients (Bradley 2010). Another potential reason high elevation sites were invaded less in the present study is that higher elevation sites were remote, isolated from anthropogenic influences that may increase the probability of *B. tectorum* invasion (Bradley and Mustard 2006).

There is limited research available on the effect of *A. thurberianum* on *B. tectorum* and the current work expands upon it. Goergen et al. (2011) found that *A. thurberianum* decreased *B. tectorum* biomass, but less so them other native perennial bunchgrasses. Reisner et al. (2013) noted that communities with *P. spicata*, *A. thurberianum* and *P. secunda* decreased *B. tectorum* cover by limiting the availability nutrients and space for recruitment. *Achnatherum thurberianum* was included in the best fit NPMR model for *B. tectorum* density. Both *B. tectorum* density and *A. thurberianum* cover increased at low levels suggesting an ecosystem without competition for limited resources. Once *A. thurberianum* reaches a relatively low cover (1%) *Bromus* density is inhibited. This could indicate competition with *A. thurberianum* or competition with other species in the community. The NPMR is unable to clarify whether *A. thurberianum* is inhibiting *B. tectorum* density on its own, if it is limiting resources in tandem with other species, such as *P. secunda*, or acting as an indicator species for a different species or mechanism. Given previous research, it seems likely that *A. thurberianum* is at least contributing to the inhibition of *B. tectorum* density. The NPMR model with total native perennial bunchgrass cover and density in the predictor matrix lends credence to that conclusion.

The native perennial bunchgrass cover inhibited *B. tectorum* cover. The sensitivity of native perennial bunchgrass cover was greater than that of the *E. elymoides* cover indicating a change in native perennial bunchgrass cover will have a greater effect on *B. tectorum* cover than *E. elymoides*. Others have also noted native perennial herbaceous cover can suppress *B. tectorum* (Chambers et al. 2007, Condon et al. 2011). In work examining the effect of mechanical and fire removal of woody fuels, twenty percent cover of native perennial plants, including forbs, prior to treatment was shown to inhibit *B. tectorum* up to three years post-treatment (Chambers et al. 2014). Though we do not have pre-fire data, *B. tectorum* cover was inhibited when extant stands of native perennial bunchgrass was at 20% or greater.

The fact that *Agropyron cristatum* did not have a significant linear relationship with *B. tectorum* nor was identified as important in the NPMR analyses is surprising. *Agropyron cristatum* is considered an excellent competitor. It out competes many native perennial bunchgrass species (Marlette and Anderson 1986, Gunnell et al. 2010, Hulet et al. 2010, Nafus et al. 2015) and was identified as one of the few species that can inhibit *B. tectorum* growth (Aguirre and Johnson 1991), biomass (Yoder and Caldwell 2002), or reproduction (Yoder and Caldwell 2002). One study does suggest that *B. tectorum* hindered establishment of *Agropyron cristatum* (Shown et al. 1969). Our results indicate that although *Agropyron cristatum* may slightly inhibit *B. tectorum*, other bunchgrasses are needed for there to be a significant effect at landscape scales.

Implications for Management/Policy

Bromus tectorum has played a role in the increase of wildfire size throughout the west and the need to control its spread was identified in the Integrated Rangeland Fire Management Strategy (Jewell 2015). The historic widespread use of *Agropyron cristatum* in rangelands has inhibited the establishment of native species such as *E. elymoides* and *A. thurberianum* that were identified in the present research as important to reduce *B. tectorum* cover. Land managers should consider increasing the seeding rate for native perennial bunchgrass species to increase their cover more quickly. *Agropyron cristatum* is useful as one component of a holistic seeding strategy, but it should not be the dominant species in the seed mixes if reduction of *B. tectorum* cover is a management goal.

Future Research

There may be an effect of elevation on the slope of the linear regressions. Elevation was the most important variable affecting *B. tectorum* cover, with slight changes in elevation resulting in changes in *B. tectorum* cover. An analysis of covariance may reveal that the relationship between *P. secunda*, *Agropyron cristatum*, and *E. elymoides* vary at different elevations. The number of seeding treatments or time since most recent seeding may also alter the relationship between these species. A new experiment that takes advantage of wildfires or a series of prescribed fires along an elevational gradient should be conducted that uses post-fire rehabilitation seedings dominated by native perennial bunchgrasses. This would help us determine if native perennial bunchgrasses are as effective at inhibiting *B. tectorum* as this research project suggests.

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Appendix A

Contact Information for Key Project Personnel

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Appendix B

Articles in peer-reviewed journals

Bowman-Prideaux, C., E.K. Strand, and B.A. Newingham. In Prep. The effect of perennial bunchgrasses on *B. tectorum* cover and density.

Doctoral Thesis

Bowman-Prideaux, C. The effect of fire and post-fire rehabilitation on plant community susceptibility to *B. tectorum* invasion. Expected Spring 2018.

Conference or symposium abstracts

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.

Gicklhorn, J.M., C. 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., C. 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.

Dodge, J., C. Bowman-Prideaux, E.K. Strand, and B.A. Newingham. 2016. Pointing cheatgrass out the door: Analyzing spatial distributions among annual invasive species 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 – Fire Ecology & Management Congress. San Antonio, TX.

Appendix C

Metadata (when applicable): Metadata must be provided when specified in the project's data management plan as part of the final report submittal. The metadata input field is located on the Final Report tab. Acceptable file types for metadata are: .xlsx, .xls, .xml, .html, .docx, .doc, and .txt. The metadata themselves do not need to be included in this appendix. This appendix should simply describe the nature of the data and metadata collected and prepared by the project, indicate where both are or will be archived, and describe and justify any deviations from the project's original data management plan.

Appendix D

Table 2 Species used in the NPMR analyses and the number of sites each species was found. The cover and density for each species was used in the predictor matrix. *Bromus tectorum* cover and density was used in the response matrix.

Function Group	**Species**	**Sites (n)**
Native perennial bunchgrass	*Poa secunda* J. Presl	66
	Elymus elymoides (Raf.) Swezey	33
	Pseudoroegneria spicata (Pursh) Á. Löve	20
	Achnatherum thurberianum (Piper) Barkworth	14
	Festuca idahoensis Elmer	7
	Elymus wawawaiensis J. Carlson & Barkworth	6
	Achnatherum hymenoides (Roem. & Schult.) Barkworth	4
	Leymus cinereus (Scribn. & Merr.) Á. Löve	4
Native forbs	*Phlox aculeata* A. Nelson	33
	Phlox hoodii Richardson	17
	Astragalus species L.	9
	Erigeron species L.	8
	Lupinus species L.	8
	Calochortus bruneaunis A. Nelson & J.F. Macbr.	6
	Epilobium brachycarpum C. Presl	5
	Linum lewisii Pursh	5
Native annual grass	*Vulpia* C.C. Gmel.	11
Native shrubs	*Artemisia tridentata* Nutt. ssp. *wyomingensis* Beetle &	23
	Chrysothamnus viscidiflorus (Hook.) Nutt.	19
Nonnative perennial bunchgrass	*Agropyron cristatum* (L.) Gaertn	47
Nonnative forb	*Sisymbrium altissimum* L.	40
	Salsola tragus L.	32
	Ceratocephala testiculata (Crantz) Roth	22
	Tragopogon dubius Scop.	17
	Descurainia sophia (L.) Webb ex Prantl	16
	Chondrilla juncea L.	13
	Lepidium perfoliatum L.	6
	Medicago sativa L.	5
Nonnative annual grass	*Bromus tectorum* L.	56

Table 3 Geospatial abiotic data extracted for sites and used in the predictor matrix for the NPMR.

	Attribute	Progress
Climate[1]		
	Mean annual precipitation	PRISM
	Mean high temperature	PRISM
	Mean low temperature	PRISM
Elevation[2]		
	DEM Elevation	USDA NRCS GeoSpatial Data Gateway
Rehabilitation Treatment[3]		
	Total number	All rehabilitation data was extracted or derived from multiple sources: Shapefiles from Jarbidge and Bruneau Field Office, BLM, Idaho Shapefile from National Operations Center, BLM, Downloaded from Inside Idaho Shapefiles from Mountain Home Air Force Base, DOD
	Time since most recent	
	Number of drill seedings	
	Time since most recently drilled	
	Time since first drill seeding	
	Year first drill seeded	
	Number of aerial seedings	
	Time since most recent aerial seeded	
	Time since first aerially seeded	
	Year first aerially seeded	
	Presence/Absence of herbicide	
	Time since last herbicide application	
	Year herbicide was first applied	
	Treatment size	
	Proximity to intact habitat	
	Site distance to treatment edge	
Fire History		
	Fire name	All fire data was extracted or derived from shapefiles found on Inside Idaho: Historic Fire Perimeters, BLM Current Year Fire perimeters, BLM
	Fire year	
	Time since most recent fire	
	Time between 2 most recent fires	
	Time since first fire	

1- 30 year means

2- DEM will be verified using GPS elevation data collected in the field during the 2015 season

3- Treatments verified using data from BLM field offices.