# The Effects of Fall and Spring Prescribed Burns on the Control of Cheatgrass and Japanese Brome in Boulder County, Colorado

**2005 Draft Project Report**
Prepared for Boulder County Parks and Open Space
By the Denver Botanic Gardens' Research, Herbaria and Records Department

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## ABSTRACT

Cheatgrass and Japanese brome are the dominant invasive species of concern for this study, although several additional state-listed noxious weeds were documented during the vegetation sampling. Cheatgrass is a winter annual, maturing in early spring before its native grass counterparts and out competing these species for water and space. Cheatgrass can alter the natural fire cycle by modifying the frequency, seasonality, and severity of natural and prescribed fires. These blazes may be disproportionately detrimental to natives and potentially beneficial to cheatgrass, although appropriately timed prescribed burns may provide opportunities for native plants to out compete the exotics. Using ocular point-cover estimates, we documented the changes in species richness and percent vegetation cover following spring and fall prescribed burns at three study sites. Applied experiments of this type provide valuable information to promote effective methods of invasive species control and the conservation of existing natural areas.

Decreases or suppression of *Bromus* species were documented at the three sites, although the prescribed fire treatments were only statistically significant at two of the sites. In general, vegetation cover, species richness, and similarity of plant communities all increased over time. This may be due to recovery from the recent drought cycle, which was most devastating in 2002. Therefore, year and the implicit abiotic conditions associated with time also had strong influences in the dynamic plant communities. Although the fall burn treatment could only be applied to one site, it suppressed the explosion of *Bromus* seen in the control treatment, but to a lesser degree than the spring burn treatment. In the short-term, the spring and fall burn treatments reduced or controlled the invasion by annual bromes, but also appeared to suppress species richness in comparison to the control treatments.

## INTRODUCTION

In the spring of 2003, Denver Botanic Gardens (DBG) and Boulder County Parks and Open Space (BCPOS) initiated a multi-year project to study the effects of spring and fall prescribed burns as a tool to control the invasion of cheatgrass (*Bromus tectorum* L.) and Japanese brome (*Bromus japonicus* Thunb. ex Murr.) at the Rabbit Mountain Open Space Park in northern Boulder County. This project is funded by the Boulder County small grant program. Due to inclement weather and sheriff’s fire bans, all planned prescribed burns could not occur as planned; therefore a second study site, which we will refer to as Rabbit Mountain Meadow, was installed, burned and sampled at Rabbit Mountain Open Space in 2004. Additionally, a third study site was installed in 2004 at Lindsay Meadow (City of Boulder Mountain Parks and Open Space) in southern Boulder County. Identical sampling methods were implemented at each site, although Boulder County funds were not utilized for the sampling of the City of Boulder property. This report summarizes the experimental methods and analysis of the data using non-metric multidimensional scaling and a split-plot ANOVA to evaluate the results of prescribed fire on the three study sites

Much debate surrounds the success of using fire to control cheatgrass and other annual brome species. Many variables factor into this debate and effective management practices must be sensitive to specific sites and circumstances, including previous management actions, intensity of the invasion by exotics, and abiotic factors such as fine litter moisture content, climate, and soils. A disturbance, such as overgrazing or modification of the natural fire cycle, may facilitate the initial invasion of adventives species such as *Bromus tectorum* and *B. japonicus*. Removal of the disturbance will allow the natives to rebound, but will not result in displacement of the non-native species (Keeley, 2001). Controlled burns are often used as an effective, non-chemical method to control targeted adventive species. However, the timing of the controlled burn can have a detrimental effect on native species and can increase the fecundity of invasive species, especially in the case of cheatgrass. Optimal timing of the burn can decrease the production of cheatgrass, at least in the short-term (Young, 1978). Frequency of fires can also affect the spread and dominance of cheatgrass, as well as the amount of nitrogen in the soil. This research project will determine if differences occur in the frequency of cheatgrass and Japanese brome, based on spring versus fall prescribed burns. Limited soil samples have been analyzed to determine the affect of fires on the soil nutrient composition and soil seed bank, although the greenhouse component of this work is still underway.

Spring prescribed fires occur at a time when the burn will destroy cheatgrass before it is able to release seeds, but will not harm the natives, which have yet to commence above ground growth. Overall, cheatgrass populations show an initial decline after these burns, but studies have shown that individual plants surviving these burns are more fecund and robust (Young, 1978). Fall burns have a similar effect of reducing the following generation, presumably by killing fall germinating seedlings of annual bromes (winter annuals) or reducing the soil seed bank due to high heat. In the absence of reseeding with native species or additional management, a return to infested, pre-burn conditions occurs after three to four years (Nature Conservancy, 1999). The soil seed bank plays an important role in the life cycle and establishment of annual bromes. The original scope of this project does not study the seed bank or the effect of prescribed burns on the survivorship of dormant seeds in the soil. A side project is currently underway to propagate the soil seed bank from the experimental fire treatments. This data is not included in the report.

Many organisms have evolved mechanisms to alter their environment to one more favorable to their needs. This process of niche construction allows invasive grass species to increase the frequency and intensity of the fire regime (Keeley, 2001). Cheatgrass, like many non-native species, completes its life cycle early in the growing season. This allows it to monopolize early season soil moisture and then senesce when natives are beginning their growing season. Dry cheatgrass is extremely flammable and can shorten the fire cycle dramatically by increasing the chance of ignition and the rate of spread of wildfires (Young, 1995). Wildfires release an abundance of nutrients, including nitrogen, from the volatized biomass. Cheatgrass is favored in nutrient rich soils, while natives and late seral species are more tolerant of lower nitrogen levels (Pyke, 2002). By examining the results of different prescribed burns (spring versus fall), Denver Botanic Gardens will be able to make research based management recommendations for restoring natural grasslands and controlling the invasion of the non-native brome species.

## METHODS

**Study Sites –** Upon acceptance of Denver Botanic Gardens' proposal in January of 2003, Claire DeLeo (BCPOS) and DBG staff began surveying BCPOS properties that match the requirements of the project. Currently, two study sites have been sampled at Rabbit Mountain Open Space and one site at Lindsay Meadow Open Space.

> **Site 1: Rabbit Mountain –** In 2003, a large southwest-facing hillside at Rabbit Mountain Open Space was chosen as the study site for both the spring and fall prescribed burns. The hillside is dominated by cheatgrass and Japanese brome, although many native forbs and graminoids are present. The study site is located due south of the intersection of the Eagle Wind trail and St. Vrain Supply Canal road. The approximate elevational range is 1706 to 1753 meters and the following coordinate marks the approximate center of the sampling area (UTM 4455178N 481585E NAD27, elevation 1737m).

**Site 2: Rabbit Mountain Meadow** – In 2004, a second study area was installed in an open meadow past the eastern most edge of the Eagle Wind loop trail. In March of 2004, a prescribed burn occurred in Unit 53, but the adjacent fall burn could not be completed. A second spring burn treatment was applied to the site in March of 2005, although the conditions were not appropriate and the fire could not support itself. The eastern portion of the meadow is dominated by non-native brome species, *Rhus trilobata* (Shunkbrush), and numerous native graminoids and forbs.

**Site 3: Lindsay Meadow** – In 2004, an open meadow surrounded by ponderosa pines (*Pinus ponderosa*) on the City of Boulder Mountain Parks and Open Space property in south Boulder County was chosen. The meadow contains many native graminoids in addition to the non-native brome species and a large stand of musk thistle. *Bromus japonicus* and *Poa pratensis* L. are the dominant non-native graminoids. Funds from Boulder County were not used to sample the Lindsay Meadow site.

**Prescribed Fires and Sampling Schedule** - BCPOS or City of Boulder staff conducted all prescribed burns following submission of a burn request form. Data collection was completed by DBG staff and interns.

**Site 1 Prescribed Burns** (Rabbit Mountain – BCPOS)
Spring burn treatment – March 10, 2003
2003 Summer Sampling
Fall burn treatment – September 24, 2003*
***Burn did NOT overlap with sampled transects**
2004 Summer Sampling – ONLY two control transects sampled
2005 Summer Sampling

**Site 2 Prescribed Burns** (Rabbit Mountain Meadow – BCPOS)
Spring Burn treatment (Burn Unit 53) - March 22, 2004
2004 Summer Sampling
Fall burn treatment 2004 - prescribed burn could **NOT** be implemented
Spring burn treatment repeat- April 7, 2005 (Burn Unit 53)
2005 Summer Sampling
Fall burn treatment 2005 - prescribed burn could **NOT** be implemented

**Site 3 Prescribed Burns** (Lindsay Meadow – City of Boulder)
Fall burn treatment (fire escaped) - September 16, 2004
2004 Summer Sampling
Spring burn treatment - April 19, 2005
2005 Summer Sampling

**Sampling Methods** – Point cover using an ocular scope and 25 meter transects is the primary sampling technique. Each study site has three experimental treatments (control, spring burn, fall burn) applied to ten transects, therefore each treatment has a sample size (n) of ten transects. This type of point-cover measurement is useful for assessing vegetation based upon the ease of implementation and the morphology of the plants, especially graminoid leaf morphology (Elzinga, 1998). Point-cover measurements allow all species (native and non-native) and abiotic elements to be monitored. Additionally, point-cover measurements are generally stable regardless of the timing of data collection, i.e. spring versus late summer (Elzinga, 1998). At half-meter intervals, the point-cover was noted on both sides of the transect. Subjectivity of 'hit' placement is diminished by using the ocular point-cover devices borrowed from Boulder County Parks and Open Space and the City of Boulder Mountain Parks and Open Space. The plant species or abiotic object found at the junction of the cross hairs is considered the "hit" for the point-cover data point and each transect contains 100 'hits', although some variation occurs within the total number of hits per transect due to human error. Percent cover for all living plant material and abiotic elements (rock, standing dead vegetation, litter and bare soil) were determined for each 25m transect based upon measurements on both the left and right sides of the transect at half meter intervals. Standing dead refers to previous years' remaining plant material that is upright and litter is considered any dead, unconnected plant material located on the ground. Modifications to the experimental design were made following the 2003 sampling due to difficulties overlapping the fire and sampling areas. Appendix A lists the mean percent cover for all species within a treatment. The specifics of the sampling design for each site are addressed below.

> **Site 1 - Rabbit Mountain:** A central point of origin was selected in the spring burn and another within the potential fall burn area. The starting point of each 25 meter transect was determined from these points of origin by a randomly chosen compass bearing (degrees) and distance (between 0 and 30m). From this point, another randomly chosen compass bearing was selected for the orientation (direction) of the transect; therefore transect placement and direction are random. A total of 21 transects were installed and sampled at this site in 2003, although only four transects were resampled in 2004 due to time constraints and prioritization of site 2 over site 1. All transects were sampled in 2005. Density of cheatgrass and Japanese brome were measured in five transects during 2003, although this sampling technique was abandoned due to the large amount of time required to complete and the similarity of data collected to the point-cover method. Five density sub-plots were selected within five transects by a stratified random sampling method for the determination of cheatgrass and Japanese brome density. At each plot a 25cm X 100cm frame was used to count the number of individual cheatgrass (*Bromus tectorum*) and Japanese brome (*Bromus japonicus*) plants, therefore determining density (number of plants per area).
>
> **Site 2 - Rabbit Mountain Meadow:** An identical ocular point-cover sampling technique was implemented at the second site in 2004, but the positioning of transects

> was modified to facilitate overlap with the prescribed burns. Three macroplots (each 11 x 25 meters) were installed along the eastern edge of the meadow, each oriented in the same direction. Each macroplot contains ten parallel and randomly positioned 25 meter transects, therefore the sampling method is identical to Study Site 1, but the parallel placement of transects within macroplots made it easier to incorporate the sampled areas into BCPOS' burn plan. Each macroplot received a specific burn treatment (control, spring burn, or fall burn) and includes ten transects.
>
> **Site 3 - Lindsay Meadow:** Identical sampling design and methodologies as study site 2, except macroplots are adjacent (2m between each macroplot). Only two control transects were sampled in 2004.

In order to describe the vegetation community for each site, total percent cover and mean vegetation cover are represented in stacked histograms for all treatment and year combinations (Figures 1 and 2, respectively). Species richness values and Jaccard's Index of Similarity were determined for all year and treatment combinations at each site (Table 1). The similarity indices are a simple mathematical expression for the similarity of two plant communities, or macroplots, based upon the number of species in common and the number unique to each community (Mueller-Dombois and Ellenberg, 1974). Jaccard's values represent the proportion of similarity between the two samples and do not address any issues of abundance or quantity.

**Statistical Methods** - Vegetation percent cover data was grouped into floral categories of nativity (native or adventive), habit (graminoid, forbs/herbs, shrubs or trees), and life form (perennial, biennial, or annual). Ordination and classification methods were used to detect spatial patterns of the floral categories at the City of Boulder and Boulder County study sites. A dissimilarity matrix was created using the vegdist function in the R statistical program. Cluster analysis using Bray-Curtis coefficients was used to determine the level of association between floral categories between spring burn, fall burn, and control treatments over time. Cluster analysis and non-metric multidimensional scaling (NMDS) are used to graphically represent relationships between objects in multidimensional space based on new variables derived from observed differences. The stress or "badness-of-fit" between input dissimilarities and output distances in ordination space was acceptably low at three dimensions, usually below 3% (Faith et al., 2004). Therefore, variation was plotted in three-dimensional space where the axes are arbitrary and lack a quantitative scale (Figure 3). The R function, metaMDS, was used to perform the non-metric multidimensional scaling. Cluster analysis dendrograms were developed using the R function, hclust, and visually compared with NMDS plots to determine grouping or segregation of treatments or years. Greater distances between NMDS points signify a higher amount of dissimilarity, while samples with a central location and tighter grouping have more similarity of overall vegetation composition (both vegetation categories and abundance within these categories). The NMDS plots do not determine how the plant community is changing, but does indicate which samples are more or less similar in relation to one another.

Additional data analysis will include hypothesis testing of the exploratory multidimensional scaling and cluster analysis information. An analysis of similarities (ANOSIM) will be used to test if the average of the rank dissimilarities between transects within a treatment are the same as the average of the rank dissimilarities between treatments (Quinn and Keough, 2002). This analysis could not be completed prior to the submission of the annual report, although ANOVAs are used to test hypotheses.

Split-plot ANOVAs (Analysis of Variance) with treatment nested in year were used as a hypothesis test to detect statistically significant differences in the percent cover of *Bromus* species. Random effects were applied to the nested treatments, since the data represents a repeated measurement over time. The percent cover values for the two target species of the study (*Bromus tectorum* and *B. japonicus*) were combined for the ANOVA analysis and transformed for the two Rabbit Mountain Open Space sites using a square root transformation in order to meet the assumptions of normality. Combination of the two target species improved the distribution of the data and eliminated any error associated with the misidentification of the two annual brome species. Post-hoc tests used Tukey's Honest Significant Difference to determine statistical significance between years and all year/treatment combinations.

## RESULTS

**Site 1 – Rabbit Mountain**: Total percent cover represents the primary data for the study plots, including: vegetation, standing dead vegetation, litter, bare soil, and rock (Figure 1). Between 2003 and 2005, the control plot had slightly higher vegetation cover than the spring burn treatment and reduced amounts of bare soil. Over time, the percent cover of rock decreased in the control plot, presumably due to coverage by plant biomass. Figure 2 illustrates the mean vegetation cover with plant species grouped into categories based upon nativity (native or adventive), life form (perennial, biennial, or annual), and habit (graminoid, forb/herb, shrub, or tree). Regardless of treatment, the adventive annual graminoids (*Bromus tectorum* and *B. japonicus*) decreased between 2003 and 2005. Native perennial graminoids (*Stipa comata, Andropogon gerardii* and *Pascopyrum smithii*) increased over time, especially in the spring burn macroplot. An increase was also detected in the native perennial forbs/herbs. The 2004 data are not included due to the small number of transects sampled, four out of 21. Mean percent covers for all species within a treatment are listed in Appendix A and lists of plants species categorized by nativity, life form, and habit are included in Appendix B.

Non-metric multidimensional scaling (NMDS) graphically displays the grouping or segregation of the percent cover data for the vegetation categories in three dimensions. Each treatment and year combination is separated from a composite graph to simplify interpretation of the data. Over time the spring burn samples become more dispersed, meaning the vegetation community is diversifying and abundance is changing (Figure 3). The control samples remained dispersed throughout the three years of sampling. The NMDS does not determine how the vegetation is changing in species richness or abundance, since it is using multiple dimensions to determine the similarity of transect's vegetation composition while minimizing stress or badness-of-fit.

A split-plot ANOVA with treatment nested in time was used to determine statistical significance in the percent cover by *Bromus* species (*B. tectorum* and *B. japonicus*) due to year or treatment. The model for Site 1 is significant ($P < 0.0001$), but the differences are between years, not treatments according to the Tukey HSD test. Figure 4 illustrates the significant decline in *Bromus* cover between 2003 and 2005, regardless of treatment. Species richness increased in the spring burn plot (36 species in 2003 to 45 in 2005), while the control plot decreased slightly (Table 1). The increase in the spring burn treatment's richness is seen over two years. The Jaccard similarity coefficients show the highest level of similarity between the spring burn and control treatments in 2005 (57%). The lowest level of similarity occurred in contrasts between years and treatments (39% for the control 2003:spring burn 2005 comparison). Intra-year (within) comparisons tended to have the most similarity in the vegetation community.

**Site 2 – Rabbit Mountain Meadow:** Total vegetation and litter cover increased within the two control macroplots over time, while the amount of standing dead biomass decreased dramatically (Figure 1). Analogously, the percent vegetation cover decreased slightly within the spring burn transects, which were burned prior to both sampling periods. Bare soil was most prevalent in the spring burn treatment, most likely due to the volatization of standing dead biomass and litter by the spring 2004 and 2005 fires. Within the two control macroplots, increases were documented in adventive perennial graminoids and native perennial graminoids and forbs (Figure 2). A small decrease of adventive annual graminoids occurred in the second control macroplot. The amount of adventive annual graminoids decreased within the spring burn treatment from 25% to 8%, while the adventive perennial graminoids decreased by only 3%. Overall, the proportion of native plants increased in all three macroplots, although the amount of increase was smallest in the spring burn treatment.

The NMDS plots illustrate large shifts of the control treatments over time, while the spring burn treatment remains relatively stable and central (Figure 3). Segregation between all the treatments can be seen within both years, signifying that the macroplots may initially be quite different and that each site changes over time, although the spring burn transects appear to have changed the least. Besides the large decrease of annual *Bromus* species in the spring burn treatment, these results corroborate with the mean vegetation cover data.

Since the fall burn treatment could not be applied at Site 2, the *Bromus* spp. data from the control and unburned fall treatment were combined into one control treatment for the split-plot ANOVA. The model was statistically significant at P = 0.0003 (DF = 3), but the effects test of year was not significant (P = 0.1643, DF = 1). The Tukey HSD determined significance between the 2005 spring burn treatment and both the 2004 treatments. Additional differences were detected between the 2004 spring burn treatment and the 2005 control. Figure 4 illustrates decreases in *Bromus* cover in both treatments over time, but the decrease is much greater in the spring burn treatment. Species richness decreased (28 to 25 species) in the spring burn treatment, while the number of species in the two control macroplots increased slightly (Table 1). According to the matrix of Jaccard's similarity coefficients, the highest levels of similarity occur between the 2005 treatments, especially the 2005 Spring: 2005 Control A contrast (65%). Again the lowest similarities are found in contrasts that compare between both treatments and years (2004 Control B: 2005 Control A = 32%).

Surprisingly, between 2004 and 2005 the control B macroplot had the second lowest amount of similarity of all Site 2 comparisons (37%). This signifies a large amount of change in the macroplot's species composition over time, even though no fire treatment was applied.

**Site 3 – Lindsay Meadow (City of Boulder):** Total vegetation cover and litter respectively increased and decreased only slightly from 2004 to 2005 in the spring burn and control treatments and remained nearly the same in the fall burn. Mean *Bromus* species cover increased 14% and 4% respectively in the control and fall burn transects while remaining nearly the same in the spring burn treatment transects. Adventive perennial graminoids increased slightly in the spring burn (by 2%) and control (by 4%) and decreased in the fall burn (by 4%). Native perennial forbs increased in both the spring (by 9%) and fall (by 2%) treatments and decreased in the control (by 9%). Native perennial graminoids decreased in both the control (by 1%) and the fall (by 4%) while they increased in the spring (by 14%). Overall the spring burn had the most desired effect of increasing the native species while suppressing the increase of the adventive graminoids species, namely *Bromus*.

As seen by the NMDS, distinct changes in the clustering of the fall and control treatments can be visualized in Lindsay Meadow between 2004 and 2005, while the spring treatment remained centrally distributed. Since the fall burn treatment was not applied until after the 2004 sampling, we would expect to see the 2004 fall treatment bearing a strong similarity to the 2004 control samples, although only two control transects were sampled during this year. Following the 2005 fall prescribed burn, the fall treatment has become more central and similar to the spring burn treatments, signifying more similarity with the other treatments and less similarity with the tight clustering of the 2004 fall samples.

The split-plot ANOVA of *Bromus* spp. percent cover is significant at Site 2 ($P < 0.0001$, DF = 5, N = 52), although the effects test of year is not ($P = 0.2117$, DF = 1). Figure 4 illustrates the changes in percent cover and the results of the Tukey HSD post-hoc test. The only significance within treatments exists between the 2005 Control treatment and all other samples. *Bromus* cover within the three treatments was similar in 2004, but the control treatment increased significantly from 14% to 27.9% in 2005. Over time the percent cover by bromes decreased slightly (<1%) in the spring treatment, while the fall treatment increased by 4%. Species richness increased dramatically within the control treatment (13 new species) and slightly in the spring burn treatment (3) (Figure 4). The fall burn treatment decreased by 3 species in 2005, although this macroplot contained the greatest diversity during both years of sampling. According to the Jaccard's similarity coefficients, the highest levels of similarity (67%) occurred between the spring and fall burn treatments in 2005. The lowest levels were between the spring burn and control treatments in 2004 (41%) followed by the 2004 fall: control contrast. Similarity was highest between the 2005 treatments and generally lowest within the 2004 treatments, signifying a strong year effect. Overall, species richness and similarity between macroplots increased over time.

## DISCUSSION

The primary goal of this project is to determine if prescribed burns can be used to control non-native annual brome species (*Bromus tectorum* and *B. japonicus*) in the shortgrass/midgrass prairies of Boulder County and if spring or fall fires are more effective in controlling the invasive grasses. The lack of fall prescribed burns at two of the three sites made the analysis of fire's seasonality difficult, but the percent cover data provides ample opportunity to assess the effects of prescribed burns on percent cover, species richness, and similarity of communities (Jaccard's coefficients). In order to analyze the three sites and application of different fire treatments, we approached the data with three distinct analyses: percent cover for vegetation types and individual species, exploratory ordination of all vegetation categories using non-metric multidimensional scaling, and hypothesis tests utilizing split-plot ANOVAs with treatment nested in year. The multiple methods of analysis provided different insights into the complex ecosystems we are attempting to understand and manage with fire. Fortunately, the three types of analysis often revealed similar trends or detection of changes within the vegetation communities, although the inherent heterogeneity of ecosystems and the inter-annual dynamics of plant communities were also highlighted. An aspect of experimental fire studies that is not directly addressed in this project is the variability of fire and the factors implicit in determining the outcome of a prescribed fire, such as the density of plant biomass and its water content, fine litter moisture content, atmospheric humidity and wind speed. Additional investigation into the effect of these factors would greatly increase the likelihood of prescribed burns achieving the goal through the understanding of fire's effect on the soil seed bank, soil biogeochemistry, and plants of different life forms (i.e. – annuals or perennials).

In order to use a disturbance, such as prescribed fire, to control a disturbance adapted species it is critical to have a basic understanding of the plant community and how individual plant species will react to the management action. *Bromus* species are annual graminoids that can germinate in the spring or fall; therefore either a spring or fall burn can reduce the species' density or possibility of completing its life cycle (i.e. – production of viable seed), while having minimal effect on the native species which are usually dormant during these times. Overall, we documented decreases or suppression of the target species (*Bromus* spp.) at all of the three sites and often increases of desirable native species, especially perennials (Figure 2). It is important to consider the effect of the 2002 drought on the plant communities and we believe that a general trend of increased vegetation cover and species richness can be seen as the vegetation recovered from the drought, although this report does not include meteorological data. This general trend is reflected in the increased cover of vegetation seen over time (Figure 1). Site 1 had large decreases in Bromus species between 2003 and 2005, although the decrease could not be linked to the 2003 spring burn. This is the only site where the ANOVA analysis determined a significant effect of year (Effects test) and not treatment (Tukey HSD) (Figure 4). At sites 2 and 3 we documented desirable effects of fire in controlling *Bromus* species, although the two sites responded differently to the prescribed burns, possibly due to their initial vegetation composition and locations in the far north and south of Boulder County, respectively. Site 2 (Rabbit Mountain Meadow) had decreases of *Bromus* in both treatments, but the spring burn treatment showed a statistically significant effect of the burn and a greater decrease of *Bromus* species, while the control treatment was not significant. At Site 3, we documented a statistically significant increase of *Bromus* cover in the control treatment. Both the spring and fall burns at Site 3 appeared to hold the invasive grasses in check (Figure 4). The application of a fall burn treatment only occurred at Site 3 and we documented a small increase of bromes (4%), while the control increased dramatically (14%) and the spring burn treatment decreased slightly (1%). Based upon the limited data to address the effectiveness of spring and fall burns, the analysis leads us to believe that the spring burn was more effective at controlling the invasive brome grasses at Site 3. These results cannot be applied to the other locations, since the fall burn treatments were not replicated at the other sites.

Time repeatedly was shown to have a dramatic effect on the vegetation composition, probably due to abiotic factors such as precipitation and temperature, and their effect on plant competition and fecundity. The Jaccard's similarity coefficients revealed how plant communities are most similar within a year, regardless of treatment (Table 1). Likewise, the NMDS plots illustrate how macroplots change dramatically over time, often with unmanipulated macroplots varying greater than the burned sites (Figure 3). Within the three sites it appears that the burns caused the samples to become more similar (centrally located and tighter grouping), while the control samples often expressed large amounts of dissimilarity between years. No obvious trends in species richness could be associated with a treatment, due to treatments reacting differently at each of the sites. Although fire treatments appear to reduce species richness initially (Site2), they may promote more biodiversity in time. The later effect was seen in Site 1 which had a large increase in the number of species two years after the spring burn (Table 1). Site 3 had the largest increase in species richness (13 species) in the control treatment, while the spring burn treatment in Site 1 had the greatest increase (9 species). Within Site 2, species richness had very minor increases in the control treatments and a small decrease in the spring burn treatment (3).

Plant communities are dynamic entities that constantly change in species richness and abundance. Climate, disturbance regimes, and competition are a few of the primary forces directing these changes. In order to mitigate the negative effects of invasive *Bromus* species on diverse, native grasslands, we attempted to document the consequences of seasonal prescribed burns on the plant communities' species richness and diversity. The inherent heterogeneity of the plant communities within a site and large changes in abundance and richness between years made it difficult to separate the fires' effects from inter-annual variation. The decreases in *Bromus* species and ANOVA results document the ability of prescribed burns to reduce the abundance of annual bromes (Site 2) or suppress increases (Site 3). Further analysis of the NMDS data using hypothesis testing (Multiple Response Permutation Probability or Analysis of Similarity, ANOSIM) will assist interpretation of the data in a way the ANOVA cannot, since the NMDS accounts for both species richness and diversity without acknowledgement of the treatments' influence. Additionally, the application and timing of prescribed burns are important to consider for the optimization of the management actions effect. The long-term consequences of prescribed burning on *Bromus* species are critical to consider, since the invasive species may rebound from the fires and be more fecund (Young, 1978) and without additional management the sites could return to pre-fire levels within several years (Nature Conservancy, 1999).

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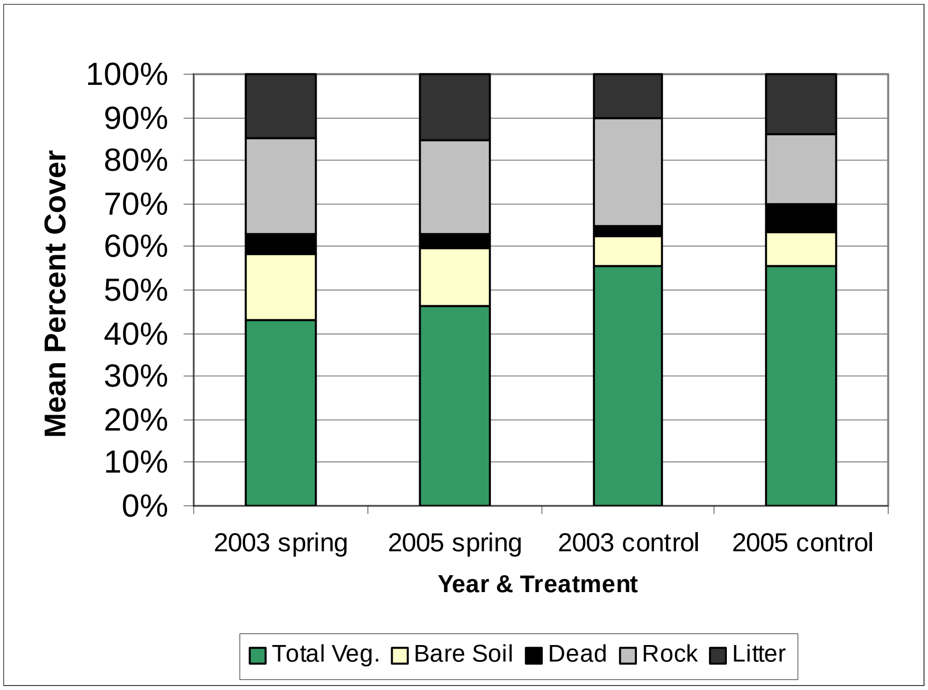
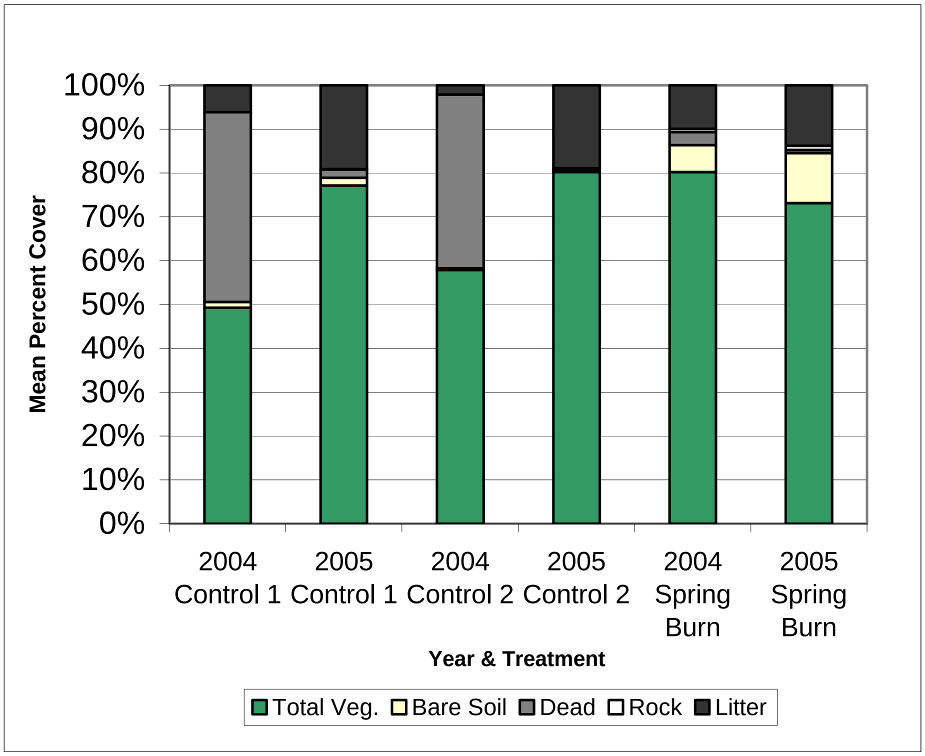
## Figure 1 – Total Percent Cover by Year and Treatment

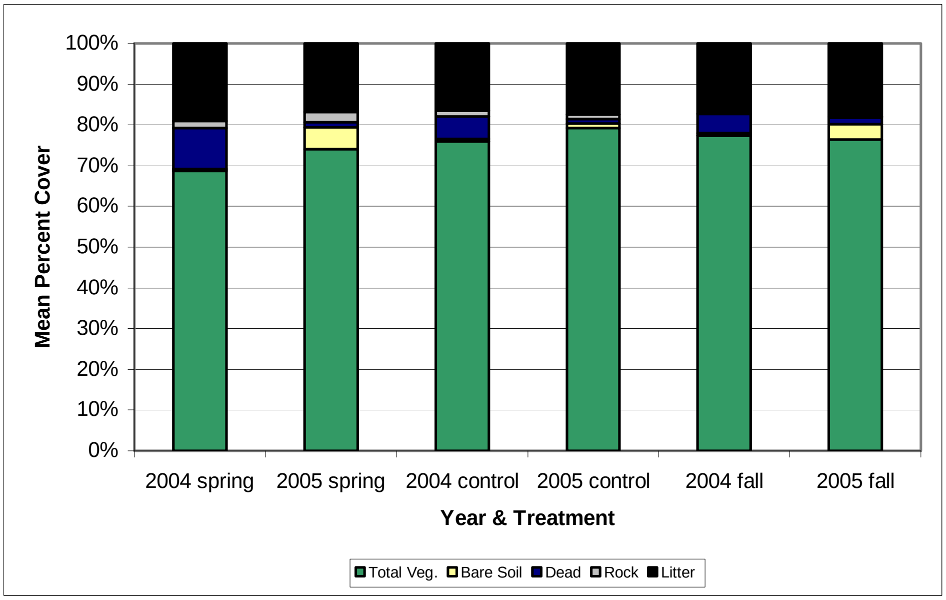
### Site 1 – Rabbit Mountain



### Site 2 – Rabbit Mountain Meadow

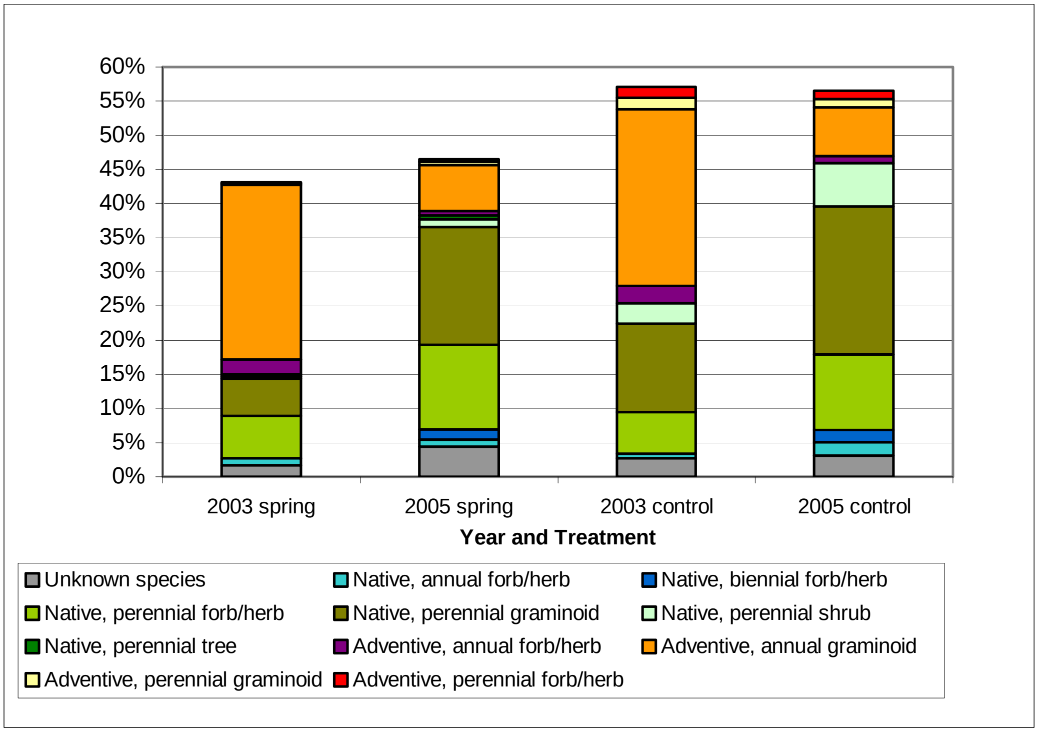


## Site 3 – Lindsay Meadow (City of Boulder)

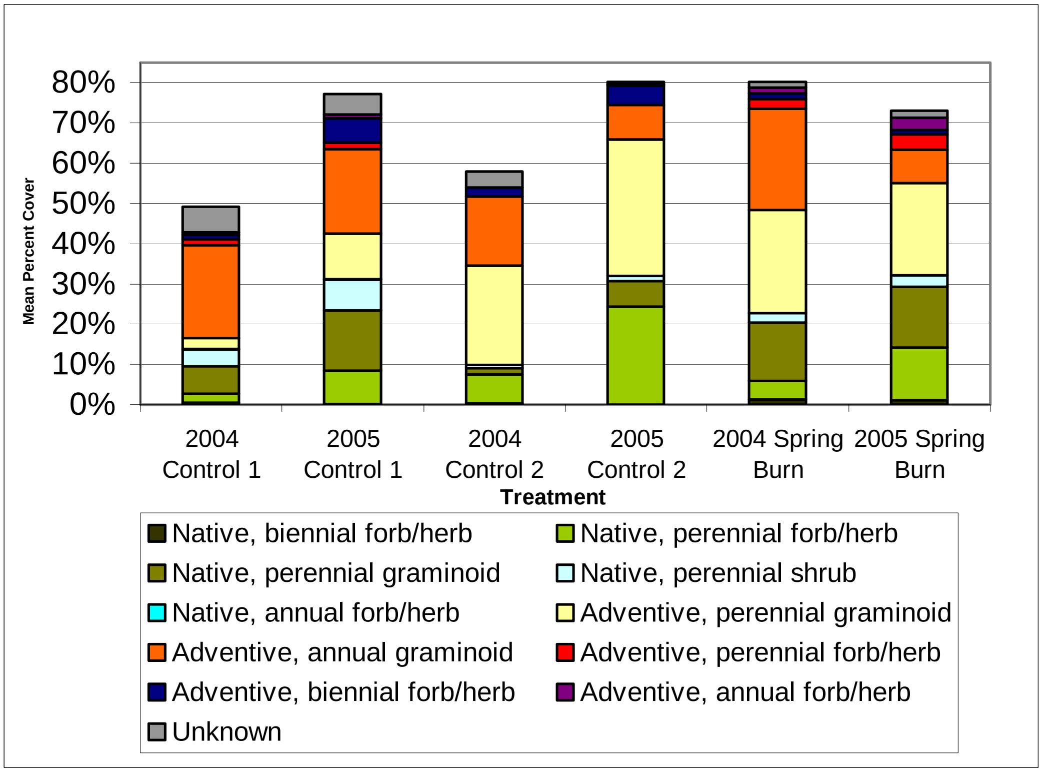


## Figure 2 – Mean Percent Vegetation Cover by Site

### Site 1 – Rabbit Mountain



### Site 2 – Rabbit Mountain Meadow



## Site 3 – Lindsay Meadow (City of Boulder)

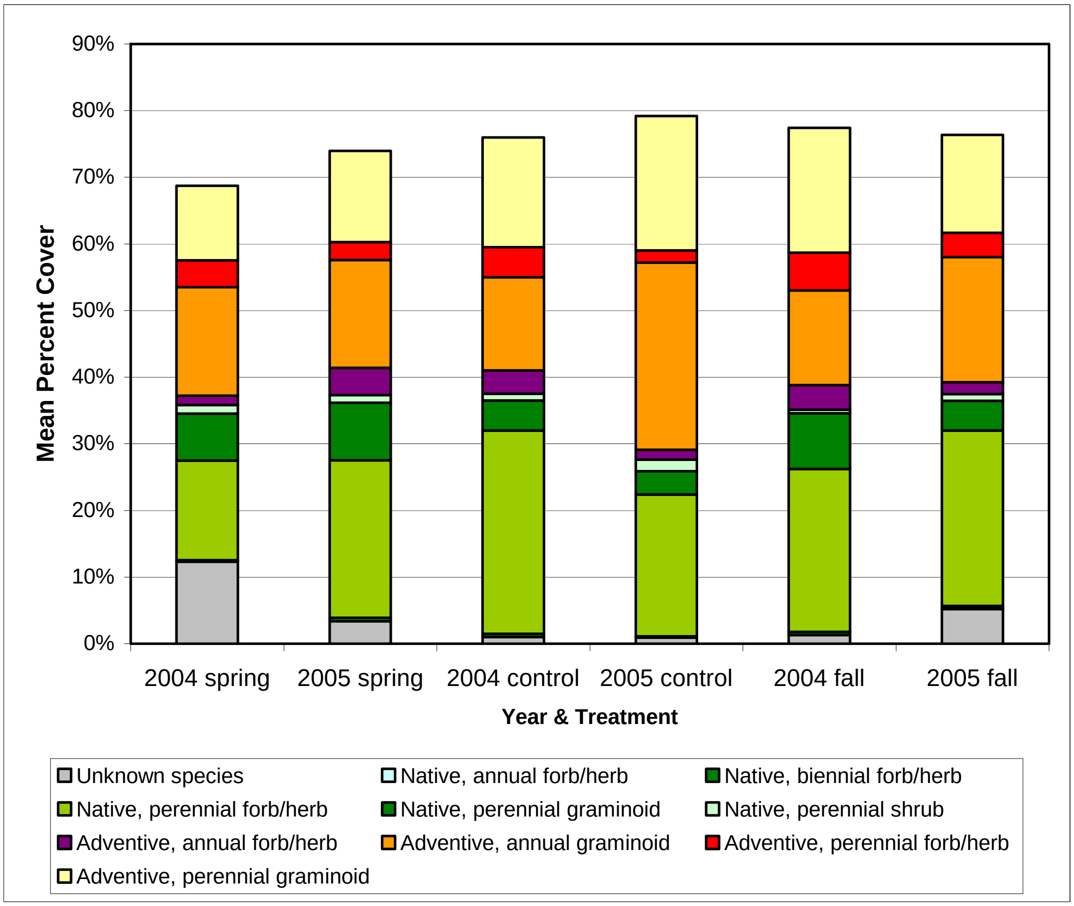
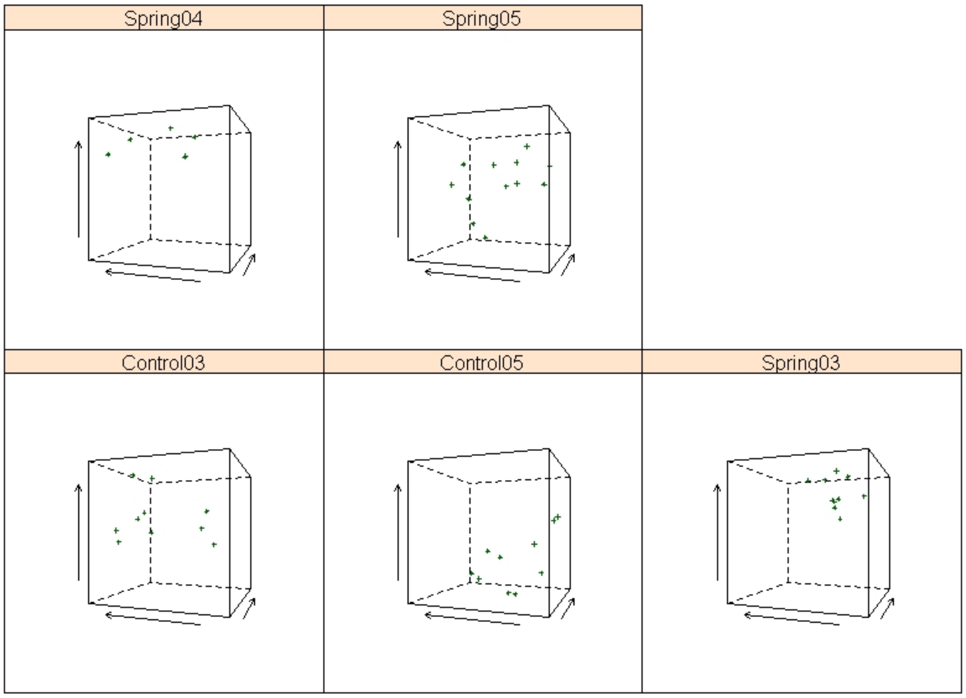


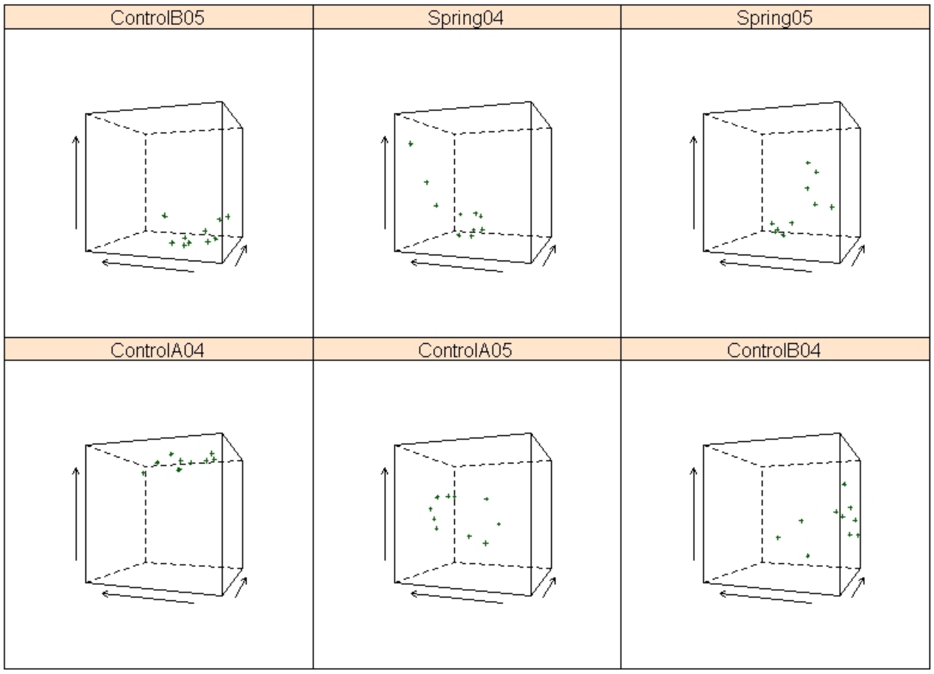
**Figure 3 – Non-metric Multidimensional Scaling (NMDS)**

Greater distances between samples signifies less similarity. In order to simplify interpretation, the NMDS results are separated. Each view represents the specified treatment (Control, Spring or Fall Burn) and year of sampling.

## Site 1 – Rabbit Mountain (2003 n=21, 2004 n=4, 2005 n=21)



## Site 2 – Rabbit Mountain Meadow (2004 n=30, 2005 n=30)



### Site 3 – Lindsay Meadow (City of Boulder)(2004 n=22, 2005 n=30)

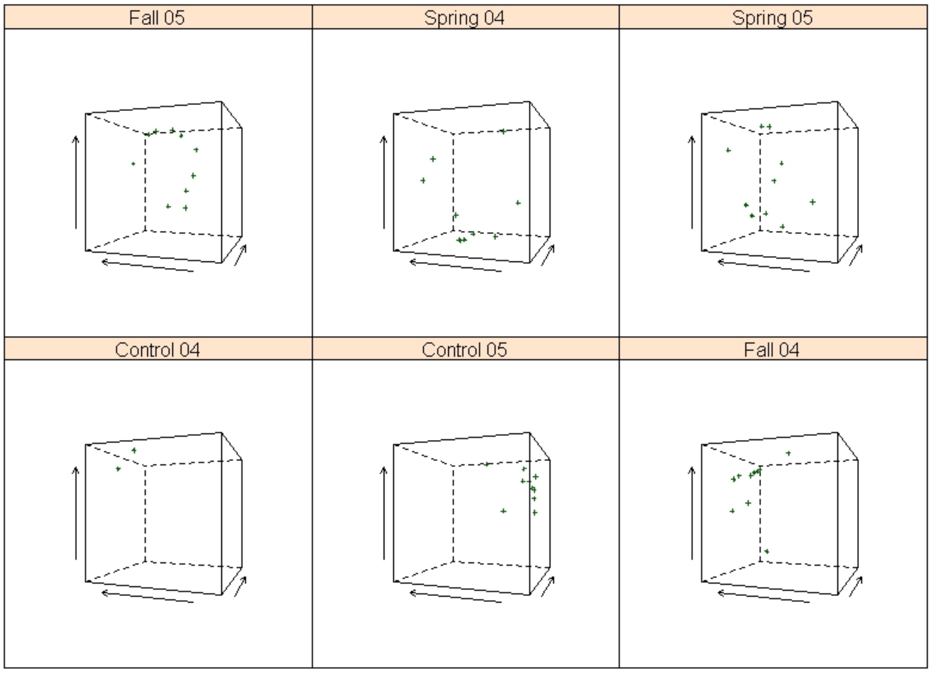
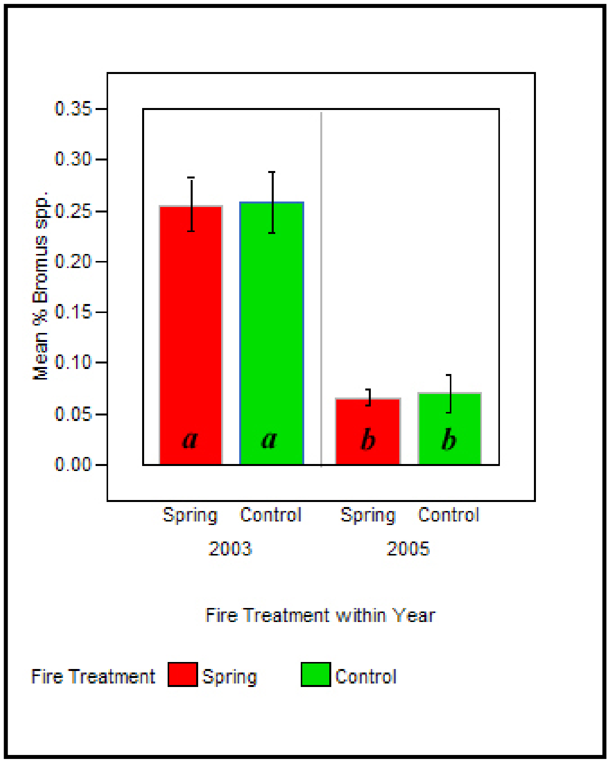
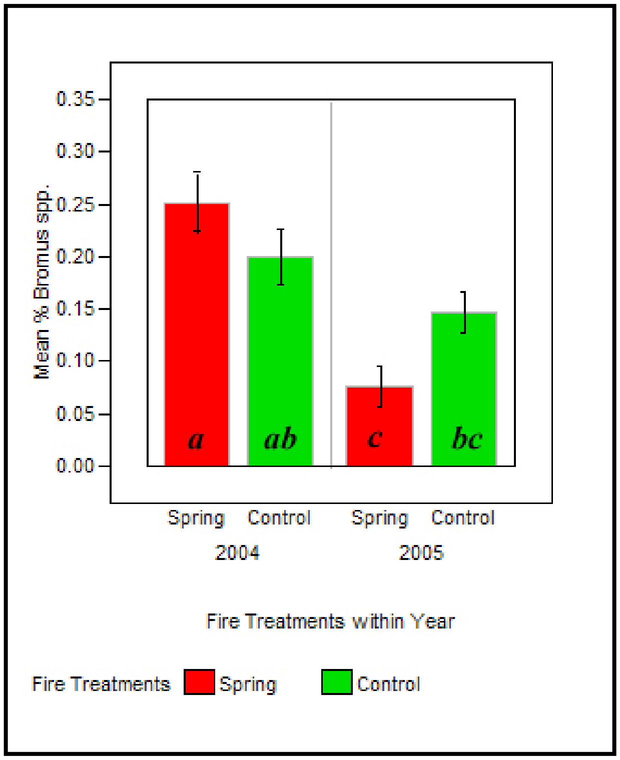


**Figure 4 – Histogram of Mean Proportion *Bromus* spp. by Year and Treatment**
Histogram bars not connected by the same letters are significantly different ($P < 0.05$) based upon the Tukey HSD post-hoc test of the split-plot Anova with treatment nested in year.

## Site 1 – Rabbit Mountain



## Site 2 – Rabbit Mountain



**Meadow**

## Site 3 – Lindsay Meadow

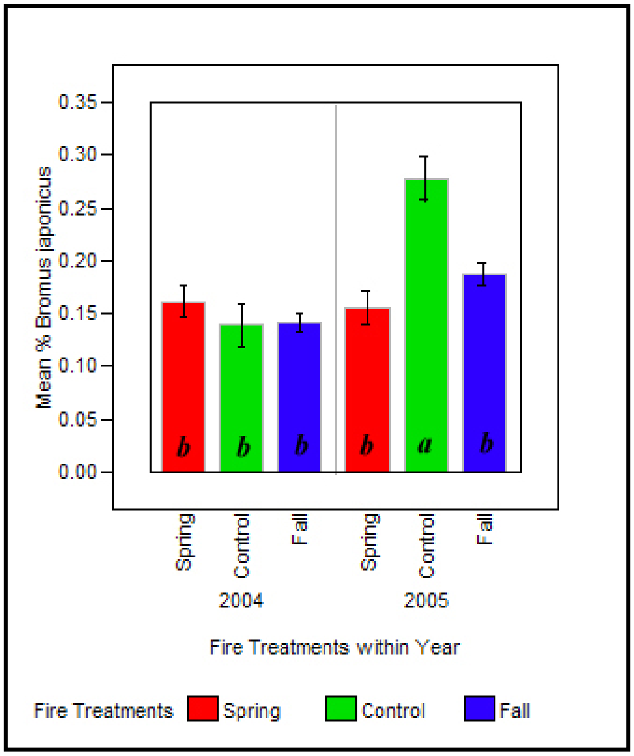


**Table 1 – Species Richness values and Jaccard's Similarity Coefficients for all year/treatment combinations.**

## Site 1 – Rabbit Mountain

| Jaccard's coefficients | Spring 2003 | Control 2003 | Spring 2005 | Control 2005 |
|---|---|---|---|---|
| Spring 2003 | - | | | |
| Control 2003 | 0.51 | - | | |
| Spring 2005 | 0.42 | 0.39 | - | |
| Control 2005 | 0.41 | 0.45 | 0.57 | - |
| | | | | |
| Species Richness | 36 | 41 | 45 | 40 |

## Site 2 – Rabbit Mountain Meadow

| Jaccard's coefficient | Spring 2004 | Control A 2004 | Control B 2004 | Spring 2005 | Control A 2005 | Control B 2005 |
|---|---|---|---|---|---|---|
| Spring 2004 | - | | | | | |
| Control A 2004 | 0.49 | - | | | | |
| Control B20 04 | 0.50 | 0.43 | - | | | |
| Spring 2005 | 0.43 | 0.38 | 0.45 | - | | |
| Control A 2005 | 0.40 | 0.45 | 0.32 | 0.65 | - | |
| Control B 2005 | 0.47 | 0.38 | 0.37 | 0.52 | 0.44 | - |
| | | | | | | |
| Species Richness | 28 | 30 | 23 | 25 | 31 | 25 |

## Site 3 – Lindsay Meadow

| Jaccard's coefficient | Spring 2004 | Control 2004 | Fall 2004 | Spring 2005 | Control 2005 | Fall 2005 |
|---|---|---|---|---|---|---|
| Spring 2004 | - | | | | | |
| Control 2004 | 0.41 | - | | | | |
| Fall 2004 | 0.54 | 0.44 | - | | | |
| Spring 2005 | 0.47 | 0.49 | 0.51 | - | | |
| Control 2005 | 0.51 | 0.50 | 0.52 | 0.64 | - | |
| Fall 2005 | 0.49 | 0.44 | 0.55 | 0.67 | 0.63 | - |
| | | | | | | |
| Species Richness | 36 | 22 | 47 | 39 | 35 | 43 |

# Appendices:

**Appendix A** – Mean Percent Cover Sampling Results by Site and Treatment (Raw Data)

**Appendix B** – Plant Species Classification List by Site

*__Due to coding within the Microsoft Access database, Sites 1 and 2 use ‘Fall’ to designate the treatment macroplot, although the fall burn treatment was not applied at either of these sites. Therefore, the ‘Fall’ treatments represent additional controls, except in Site 3.__