Treatment Effectiveness Monitoring for the Dakota Hill Complex Burned Area Emergency Response Treatments

(Pending USGS Review)

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Study 1: Understory Vegetation Response to a Post-Fire Imazapic Herbicide Application to Reduce Cheatgrass Invasion in Zion National Park, Utah

Abstract

Cheatgrass (*Bromus tectorum* L.) is an invasive annual grass that quickly dominates disturbed areas and is responsible for reduced richness and diversity of native plant communities. Although many control methods have been attempted, no one method has yet proven successful, thus some studies have turned towards the use of herbicides such as imazapic (tradename Plateau®). During the summers of 2006 and 2007, the Kolob and Dakota Hill fires burned throughout Zion National Park. In response to both fires, Burned Area Emergency Response (BAER) teams recommended landscape-scale applications of imazapic herbicide to reduce cheatgrass occurrence in the Park. The implications of such large scale applications of imazapic herbicide to burned landscapes are not fully understood. Therefore, this project monitored the effectiveness of these landscape-scale applications of imazapic in suppressing the post-fire invasion of cheatgrass and evaluates changes in the native understory plant community over a two year period. Furthermore, the germination of cheatgrass 0.5 years and 2.5 years post-application was assessed, as the treatments would be considered ineffective if the aboveground biomass and density of cheatgrass plants were reduced but the seed production and viability remained constant. The monitoring was conducted using a paired plot study (treated and untreated) in both piñon-juniper (*Pinus spp.-Juniperus spp.)* and Gambel oak (*Quercus gambelii* Nutt.) vegetation communities. Aboveground biomass, density and aerial cover were measured by species to discover the effects of the herbicide on the understory plant communities.

Although there was too little cheatgrass present in the Dakota Hill study area for significant treatment effects, results imply that imazapic does reduce the aboveground biomass, density and aerial cover of the other predominant non-native species on the site, prickly lettuce (*Lactuca serriola* L.) for two years post application. Furthermore, on both sites, native species richness, and aboveground biomass, density and aerial cover for all native species and native annual and perennial species separated were lower on treated plots as compared to the untreated plots throughout the duration of the study. Although native shrub densities were also lower on imazapic treated plots, Gambel oak was unaffected by the herbicide application. Lastly, results indicate that the understory plant communities differed between treated and untreated areas on both sites during the first two years after the herbicide application; however the communities appeared to begin converging after 2.5 years. These results indicate that a post-fire application of imazapic reduces the richness, aboveground biomass, density and aerial cover of many native species, with the effects still present two years post-application. This reduction in native plants coupled with the continued presence of cheatgrass in herbicide treated areas could actually promote cheatgrass invasion, causing the application to be ineffective or deleterious.

The germination study performed on the Kolob Fire indicated that after 2.5 years there was little change in germination potential between cheatgrass plants on treated and untreated plots. This finding suggests that the imazapic herbicide application has little effect on the ability of cheatgrass that survives the application to reproduce and colonize the site. This finding, paired

with the finding that imazapic herbicide adversely affects the native vegetation community through reducing richness, aboveground biomass, density and aerial cover of native plants suggests that in some situations the use of this herbicide could actually favor cheatgrass.

Study 1:

Understory Vegetation Response to a Post-Fire Imazapic Herbicide Application to Reduce Cheatgrass Invasion in Zion National Park, Utah

Abstract

Cheatgrass (*Bromus tectorum* L.) is an invasive annual grass that quickly dominates disturbed areas and is therefore responsible for reduced richness and diversity of native plant communities. Although many control methods have been attempted on this species, no one method has yet proven successful, thus some studies have turned towards the use of herbicides such as imazapic (tradename Plateau®). During the summer of 2007, the Dakota Hill Complex fires burned approximately 2,400 hectares in Zion National Park. In response to the fires, a Burned Area Emergency Rehabilitation (BAER) team recommended a landscape-scale application of imazapic herbicide to reduce cheatgrass occurrence in the Park. Approximately 1,300 hectares of the high severity burned landscape were sprayed by helicopter during September of 2007. The implications of such a large-scale application of imazapic herbicide to burned landscapes are not fully understood. Therefore, this project monitored the effectiveness of the landscape-scale application of imazapic in suppressing the post-fire invasion of cheatgrass and evaluated changes in the native understory plant community over a 2.5 year period. The monitoring was conducted using a paired plot study (treated and untreated) in both piñon-juniper (*Pinus edulis* Engelm.-*Juniperus osteosperma* (Torr.) Little) dominated and Gambel oak (*Quercus gambelii* Nutt.) dominated vegetation communities. Aboveground biomass, density and aerial cover were measured by species to discover the effect of the herbicide on the understory plant communities.

Although there was too little cheatgrass present in the study area to fully understand treatment effects, results imply that imazapic does reduce the other predominant non-native species on the site, prickly lettuce (*Lactuca serriola* L.), for up to two years post-application. Furthermore, on both sites, native species richness, aboveground biomass, density and aerial cover of overall native species and of annual and perennial species separated were lower on treated plots as compared to the untreated plots throughout the duration of the study. Although the density of shrubs was also lower on imazapic treated plots, Gambel oak was unaffected by the herbicide application. Lastly, results indicate that the understory plant communities on both sites differ as a result of the herbicide application. These results indicate that a post-fire application of imazapic adversely affected many native species, with many of the effects still present 2.5 years post-application. This reduction in native plants coupled with the continued presence of cheatgrass in herbicide treated areas could actually promote cheatgrass invasion, causing the application to be ineffective or deleterious.

1 Introduction

Each year, Americans spend billions of dollars in the attempt to control invasive plants (Pimentel et al. 2005). These invasive plants can cause alterations in plant community composition and biodiversity, which can affect insect and animal communities, alter nutrient and water cycles, and modify disturbance regimes such as fires (Mooney and Cleland 2001; Vitousek 1990; Young and Evans 1978). Cheatgrass (*Bromus tectorum* L.) is an invasive plant of particular concern. Introduced to North America in the late 1800s, cheatgrass has since spread to occupy over 40 million ha across the West (Mack 1981). Once introduced, cheatgrass can dominate a disturbed area within only five years (Morrow and Stahlman 1984) and in western North America is responsible for reduced richness and diversity of native plant communities (Monsen 1992) making this invasive annual grass of utmost management concern. Many methods for controlling cheatgrass have been attempted; however no one method has proven to be successful.

Recently, studies have turned to the use of herbicides to control cheatgrass, and one chemical that has shown recent promise in slowing or eliminating the spread of cheatgrass is imazapic (tradename Plateau®). According to Masters et al. (1996), the Imidazolinone herbicide family (to which imazapic belongs) is a promising group of herbicides because several native annual and perennial grasses and forbs are tolerant. Imazapic herbicide targets actively growing plant tissue, therefore shrubs and other perennials with woody or dormant tissue may be relatively unaffected by the inhibition of the amino acids (Vollmer and Vollmer 2008) and annuals would likely be affected more than perennials. Furthermore, it has the advantage of having a half-life in soil of 120 days, (with its actual length of activity potentially longer) which allows it to control weedy species throughout their growing season (Kyser et al. 2007; Tu et al. 2004), and additionally the cooler soils of the Intermountain West could result in even slower breakdown of imazapic (Kyser et al. 2007). According to Davison and Smith (2007), imazapic provided control of cheatgrass and non-native annual forbs for two years without adversely affecting native plant species in a northern Nevada sagebrush community. Meanwhile, a study in Zion National Park found that after burning, a fall application of imazapic herbicide reduced *Bromus* spp. densities by >99% in the first year, and an overall *Bromus* spp. reduction was still present in the second year post application (Matchett et al. 2009b). Unfortunately multiple studies have demonstrated that it is not only the non-natives that are affected by imazapic. Baker et al. (2009) found that in addition to the reduction in cheatgrass as a result of an imazapic application, native forbs were also affected. Furthermore, Beran et al. (1999a) found that wildflower establishment and densities could be reduced as a result of the herbicide, and Vollmer and Vollmer (2008) found an initial, though temporary, stunting of shrub species when imazapic was applied to Wyoming rangelands. Thus, if previous studies indicate that the herbicide reduces cover, density, or eliminates some native species, we would expect this study to demonstrate initial reductions in aboveground biomass, density, aerial cover and richness; however these species may recover after the herbicide has diminished from the soil.

Zion National Park, located in southwestern Utah, has recently expanded the use of imazapic herbicide to control multiple *Bromus* spp. throughout the Park. During July of 2007, the Dakota Hill Complex fires burned approximately 3,700 ha, most of which were within Zion National Park. A Burned Area Emergency Response (BAER) team assessed the impacts of the fires and made management decisions based on the threat of post-fire cheatgrass invasion from neighboring federal lands, and imazapic herbicide was applied to the high severity burned area by a helicopter in October of 2007 (Figure 1.1). Approximately 1,300 ha were treated with the herbicide, and included vegetation communities dominated by piñon-juniper (*Pinus spp.* - *Juniperus spp.*), Gambel oak (*Quercus gambelii* Nutt.), and ponderosa pine (*Pinus ponderosa* C. Lawson var. *scopulorum* Engelm.).

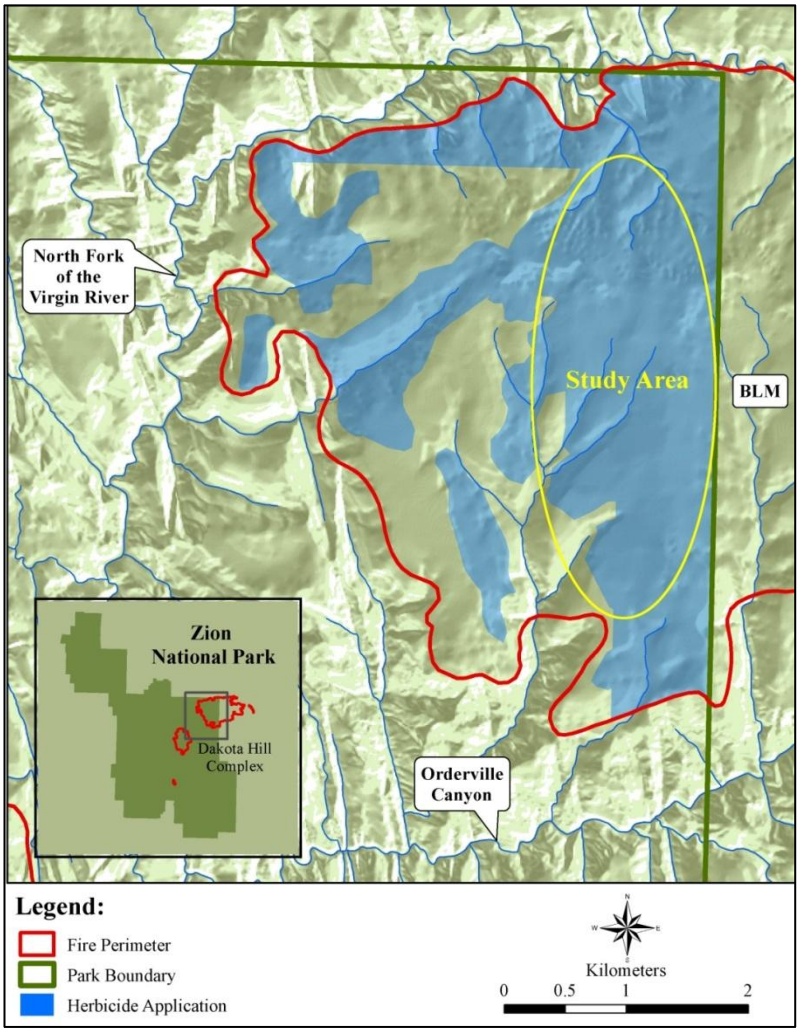


Figure 1. 1: Treatment and study area. The fire perimeter is shown in red, while the 1,300 burned ha that received an aerial application of imazapic herbicide are shown in blue. The yellow circle represents the vicinity of the study area.

Piñon-juniper woodlands cover 20-30 million ha in the western United States (West 1999). In southern Utah, these habitats are dominated by single leaf piñon (*P. monophylla* Torr. & Frem), two leaf piñon (*P. edulis* Englem.) and Utah juniper (*J. osteosperma* (Torr.) Little) (West 1999), and are the most common vegetation type in this region (Harper et al. 2003). Piñon and juniper species are valuable to wildlife for sustenance and habitat, while they are valuable to humans for fuel wood, piñon nuts and fence posts (Balda and Masters 1980). Prior to Euro-American settlement, infrequent, high intensity crown fires were natural in piñon-juniper woodlands similar to those in southern Utah, where historically it took several centuries for fuels to build up to fire-sustaining levels (Baker and Shinneman 2004; Floyd et al. 2000; Romme et al. 2008). These long fire return intervals can be attributed to the lack of horizontal continuity of fuels found in this system, where continuous grass and herbaceous cover are uncommon. Instead, these woodlands tend to be dominated by widely spaced bunchgrasses, shrubs and trees (Floyd et al. 2000). These discontinuous fuels also create a patchy environment in which fires only spread through a large area under extreme conditions (Bruner and Klebenow 1979; Romme et al. 2008). However when burned, the bare soil and open growing spaces can allow for ease of cheatgrass invasion (Harper et al. 2003). This potential invasion could lead to an annual dominated system that would likely never return to a shrubland or piñon-juniper woodland (Erdman 1970).

Gambel oak is the dominant vegetation type on 3.5 million ha throughout the four corners region of Arizona, Colorado, New Mexico and Utah (Clary and Tiedemann 1986). In the Southwest, Gambel oak is generally associated with *Pinus* spp. and can exist as dense shrubs or interspersed mature trees (Abella and Fulé 2008; Fulé et al. 2005; Laughlin et al. 2005). Although capable of reproducing by seed, Gambel oak is more commonly clonal (Simonin 2000) and sprouts readily after disturbances such as fire (Harper et al. 1985). Gambel oak has a wide range of values, benefiting native plant, insect, and animal communities, as well as humans by providing high heat-yielding fuel wood (Barger and Ffolliott 1972), and high aesthetic value. Although there is not much research on fire regimes in dense Gambel oak thickets, recent fire history research indicates that frequent spring-summer fires have been a steady fixture in Gambel oak stands throughout the Southwest (Abella and Fulé 2008); however this varies with associated plant species (Simonin 2000). In response to fire, the extensive, deeply rooted rhizomes of Gambel oak give this species an advantage after disturbance and it has been observed sprouting less than ten days after a wildfire (Tiedemann et al. 1987). If successive fires occur within a few years (as could be the case if cheatgrass were to establish), the stands may be replaced by a grass-forb ecosystem (Crane 1982); however, without successive fire, Gambel oak will reach maturity in 60 to 80 years (Simonin 2000).

1.1 Objectives & Hypotheses

The general objectives of this project were:

1. To develop a monitoring plan within the Dakota Hill Complex burned area for the effectiveness of the post-fire imazapic herbicide application as prescribed by BAER and Zion National Park
2. To locate suitable sampling sites and designate untreated controls
3. To implement the monitoring plan, collect and analyze data, communicate results to the Park and other interested parties through reports, presentations and peer-reviewed publications.

We tested the following hypotheses:

1. Herbicide treated areas would demonstrate:
    a. Fewer and smaller cheatgrass plants
    b. Initially stunted non-native and native species and lowered species richness
    c. Reductions in aboveground biomass, density and aerial cover more apparent on native annuals than native perennials
    d. An initial stunting or reduction in density of some shrub species
2. After two years, native species would show a strong recovery in treated areas due to the half-life of the herbicide and lack of cheatgrass competition in treated areas
3. The community composition of treated and untreated areas would differ since the herbicide differentially affects both native and non-native species

1.2 Kolob and Dakota Hill Linked Research

This report summarizes two components of post-fire restoration research underway in Zion National Park. This report addresses the community responses to the imazapic herbicide application to piñon-juniper dominated and Gambel oak dominated vegetation communities in the 2007 Dakota Hill Complex from spring 2008 to spring 2010 (approx. 0.5 to 2.5 years post treatment). Furthermore, this report summarizes the results of a seed germination study performed on the 2006 Kolob Fire.

Additional research is currently being completed assessing the impacts of imazapic herbicide and seeding treatments on the 2006 Kolob Fire. The objectives of this research include examination of the effects of the post-fire treatments on the aboveground brome abundance and plant community composition (Thode et al.) and the plant community seedbank (Brisbin et al.).

We plan to submit a synthesis publication from this work to describe the effects of imazapic and seeding on the understory and seedbank communities across both the Kolob and Dakota Hill fires.

2 Methods

2.1 Study Area Description

This research was conducted within the herbicide treated area in the East Fire of the Dakota Hill Complex in Zion National Park (Fig. 1.1). The herbicide was applied to approximately 1,300 ha by helicopter at a rate of 584 ml per ha (eight oz per acre) in October of 2007. It was applied within the boundary of Zion National Park to all of the high severity burned areas and also to the burned area (all severity classes) that was within a buffer of 800 m bordering Bureau of Land Management (BLM) and private land. The study area is bordered by land managed by the BLM and private holdings to the east, Orderville canyon to the south, and the North Fork of the Virgin River and the Narrows to the north and west, both in Zion National Park (Fig. 1.1).

The climate in this region is classified as semiarid (Kottek et al. 2006) with average annual precipitation of 52.90 cm from 1996 through 2009. The majority of the moisture falls as rain during the summer months, and as snow during the winter months, with the years of the study being generally drier than average (Figure 2.1). Average daily temperature for the study area ranges from a high of 19^{o}C during July to a low of -2^{o}C during December with the temperatures during study years falling near average (Figure 2.2). Climate data for this study was recorded at Lava Point, Utah, which is the most comparable weather station to the study area (http://www.raws.dri.edu). Lava Point is at an elevation of 2,347 m (approximately 300 m higher than the study area) and is located approximately 8 km away.

The vegetation communities present within the Park boundary of the East Fire of the Dakota Hill Complex are: piñon-juniper (37%), Gambel oak (30%), and ponderosa pine (27%), with the remaining burned area (6%) comprised of shrublands, grasslands, and stone formations (Gatewood 2007). This study focused on the piñon-juniper dominated and Gambel oak dominated communities due to the high burn percentages within these vegetation types and an interest by park staff in these areas.

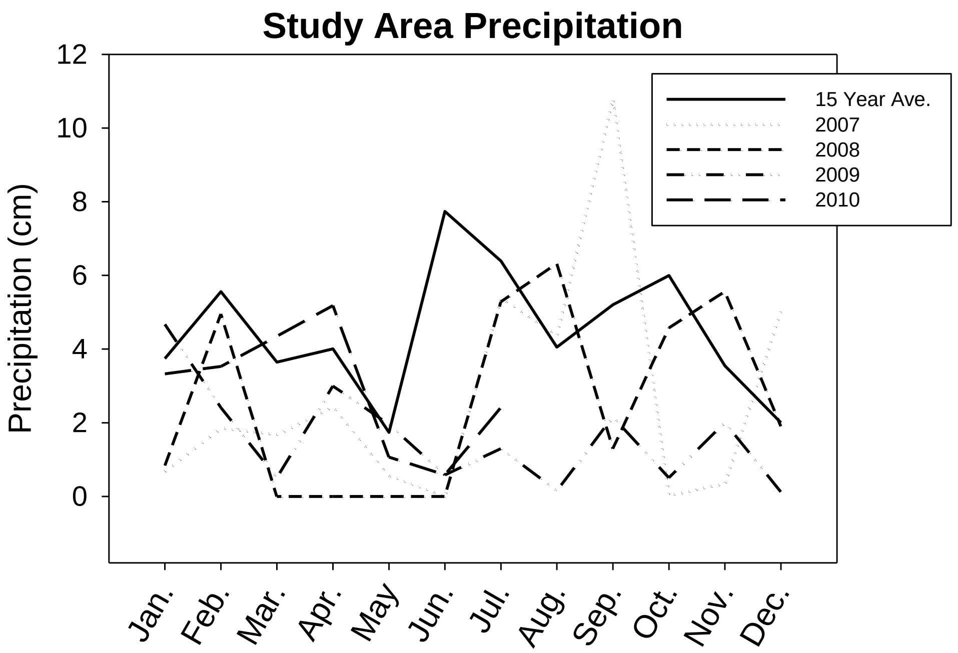


Figure 2. 1: Summary of study area precipitation from 2007-2010 in relation to the 15 year average.

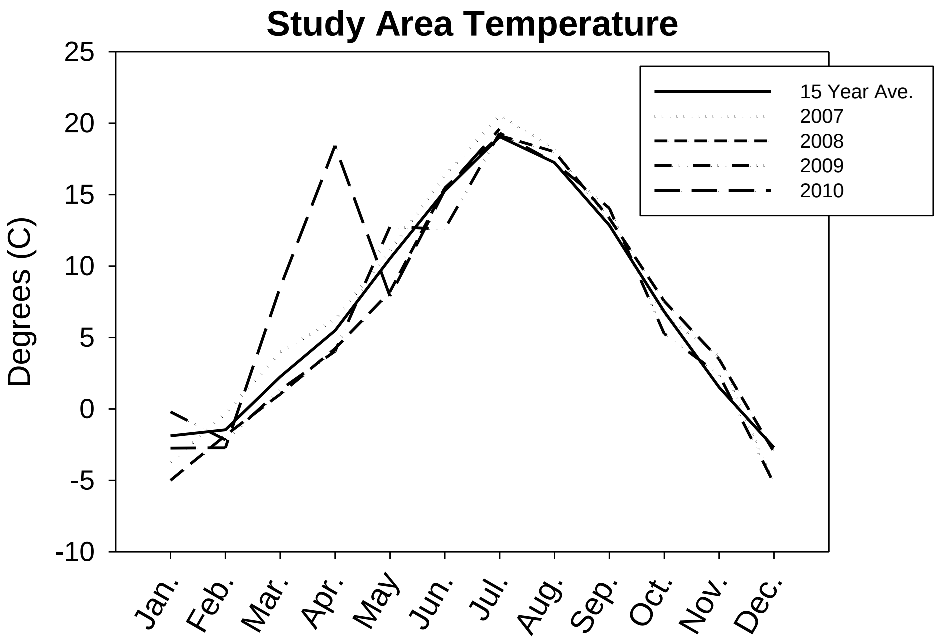


Figure 2. 2: Summary of study area temperature from 2007-2010 in relation to the 15 year average.

2.2 Study Design

The study area was stratified by vegetation, burn severity and geology (Table 2.2) and two sites were established. One site was located within high severity piñon-juniper (PJ) dominated woodlands and the other in high severity Gambel oak (GO) dominated woodlands. Burn severity was initially assessed by the BAER team using an immediate assessment of classified Landsat satellite imagery (Key and Benson 2006). Severity was then verified in the field using a modification of the Composite Burn Index (CBI) in which measurements for "intermediate trees" and "big trees" were excluded due to their absence from both piñon-juniper and Gambel oak woodlands (Key and Benson 2006). All study areas were verified as high severity. The GO site is located on the Crystal Creek member of the Carmel formation, one of the younger geological layers in the Park, and is characterized by fine-grained sandstone and siltstone (Doelling et al. 2002). The PJ site is located on the Co-op Creek member of the Carmel formation, and is characterized by residual silt, clay, and fine sand (Doelling et al. 2002).

The study consisted of a paired plot design (herbicide treated and untreated control) and all plots were established prior to the aerial application of herbicide. The plots were randomly located across the two study areas using a random point generator in Hawth's Tools (Beyer 2004) in the Geographic Information Systems (ArcGIS 9.3; ESRI, Redlands, CA), and the treatment types were randomly assigned to the paired plots (Fig. 2.1). Additional factors were taken into consideration when determining plot locations such as avoidance of large washes, slope limitations (not greater than 25^o), and proximity to unburned patches (at least 15 meters away).

The plot layout consisted of a five by 30 m plot. Since the herbicide application was done via helicopter (figure 2.3), each plot was buffered by 30 m, to insure the integrity of the control plots. This distance was chosen based on a related study of herbicide application in the 2006 Kolob Fire in Zion National Park (Thode et al. 2010). Each pair of plots consisted of an herbicide sprayed plot and an untreated control plot.

Table 2. 1: Overview of study site characteristics.

Site	# of Replicates	Elevation Range	Burn Severity
PJ	17	1950-1980 m	High
GO	16	1980-2040 m	High

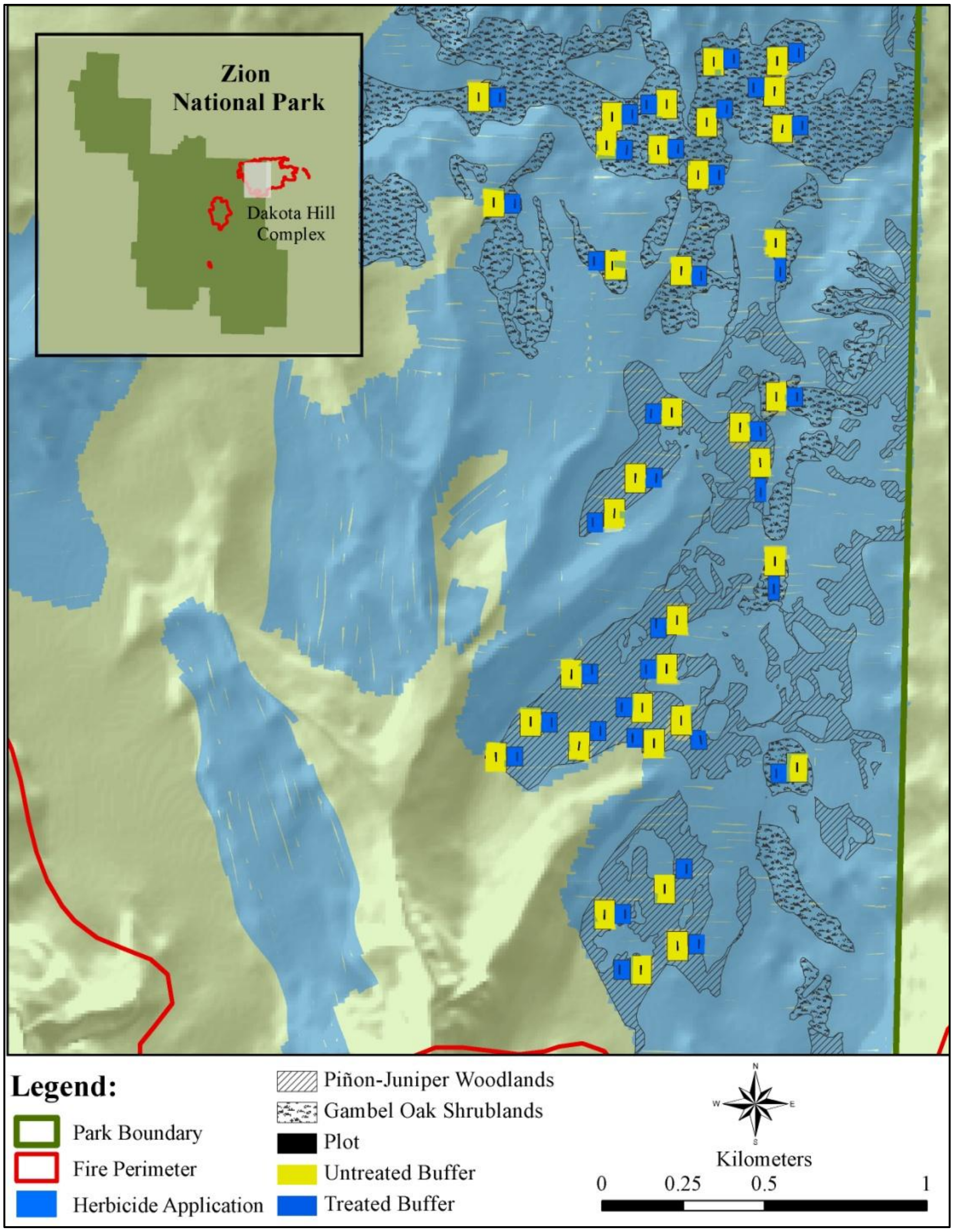


Figure 2. 3: Map of the location of plots in the study area. Blue and yellow polygons represent the buffers around the plots, which are represented by black polygons within the buffer areas. PJ woodlands within the designated geology type are represented by hash marks while the GO shrublands within the designated geology type are represented by the mottled area. The blue overlay represents the actual helicopter swaths of the herbicide application.

Figure 2. 4: Helicopter applying imazapic herbicide to the Dakota Hill Complex.

2.3 Field Methods

Sampling was based on protocols developed by the National Park Service Fire Monitoring Handbook (USDI National Park Service 2003) and used in a concurrent study on the 2006 Kolob Fire in Zion National Park. All sampling took place on the five by 30 m plot, nested within a 30 m CBI plot (Fig. 2.2). Four photographs were taken of each plot, with one overview photograph at each of the north and south ends of the plot and two photographs down the point-intersect line (the west 30 m edge of the plot), one from each end of the plot. Slope, aspect and elevation were measured on each plot to determine heat load (McCune et al. 2002b). Since a slope with afternoon sun will have higher temperatures than a slope with morning sun, heat load takes topographic variables into account to create this unitless index of solar radiation (McCune et al. 2002b).

Vegetation sampling occurred each spring and fall from the spring of 2008 through the spring of 2010. Due to time restrictions involved with the field sampling, data processing and analysis, and work necessary to complete deliverables on time, only biomass and richness were collected during the spring 2010 sampling season. Density and aerial cover by plant species, and substrate cover were measured in five one m^2 frames placed every five m along the west edge of the plot (Figures 2.5 and 2.6). Aboveground biomass was collected on five one by 0.5 m frames evenly spaced along the east 30 m edge of the plot (Figure 2.5). Due to the destructive nature of biomass sampling, subplots were shifted one m north each year. Plants were counted, clipped at ground level, separated by species in paper bags and air dried (Figure 2.7). In the laboratory, all biomass samples were further dried at 70^{o} C for 48 hours. Samples were then allowed to cool for two hours before being weighed to the nearest 0.001 g. To assess Gambel oak cover, a line-transect (Mueller-Dombois and Ellenberg 1974) was used down the west 30 m edge of the plot, as well as down the center 30 m of the plot (Figure 2.5). Shrub density and overall species richness were taken on the entire five by 30 m plot. The number and species of shrubs and trees on the plot as well as life stage (resprout, immature, mature, or dead) were measured. Species classified as subshrubs were included in the shrub category. Subshrubs on the site included toadflax penstemon (*Penstemon linarioides* A. Gray), Oregon grape (*Mahonia repens* (Lindl.) G. Don) and Oregon boxleaf (*Paxistima myrsinites* (Pursh) Raf.). Plants that could not be identified in the field were given an unknown code, collected off plot, and pressed for later identification. Those plants that could not be identified due to missing key botanical features (flowers, fruits, etc.) maintained their unknown code for richness analyses. Plant nomenclature for this study follows the USDA-NRCS PLANTS Database (2009).

Soil samples for nutrient analysis were taken each season throughout the study. These samples were collected to a depth of 10 cm using a soil corer at six locations around the plot (Figures 2.5 and 2.8). All soil cores were combined in a paper bag and air dried. Once dried, the soil was sieved through a four mm sieve and analyzed. Analyses included pH, texture, organic matter, total nitrogen and available phosphorous, and were used as a measurement of plot characteristics to be included in the environmental matrix for community analyses.

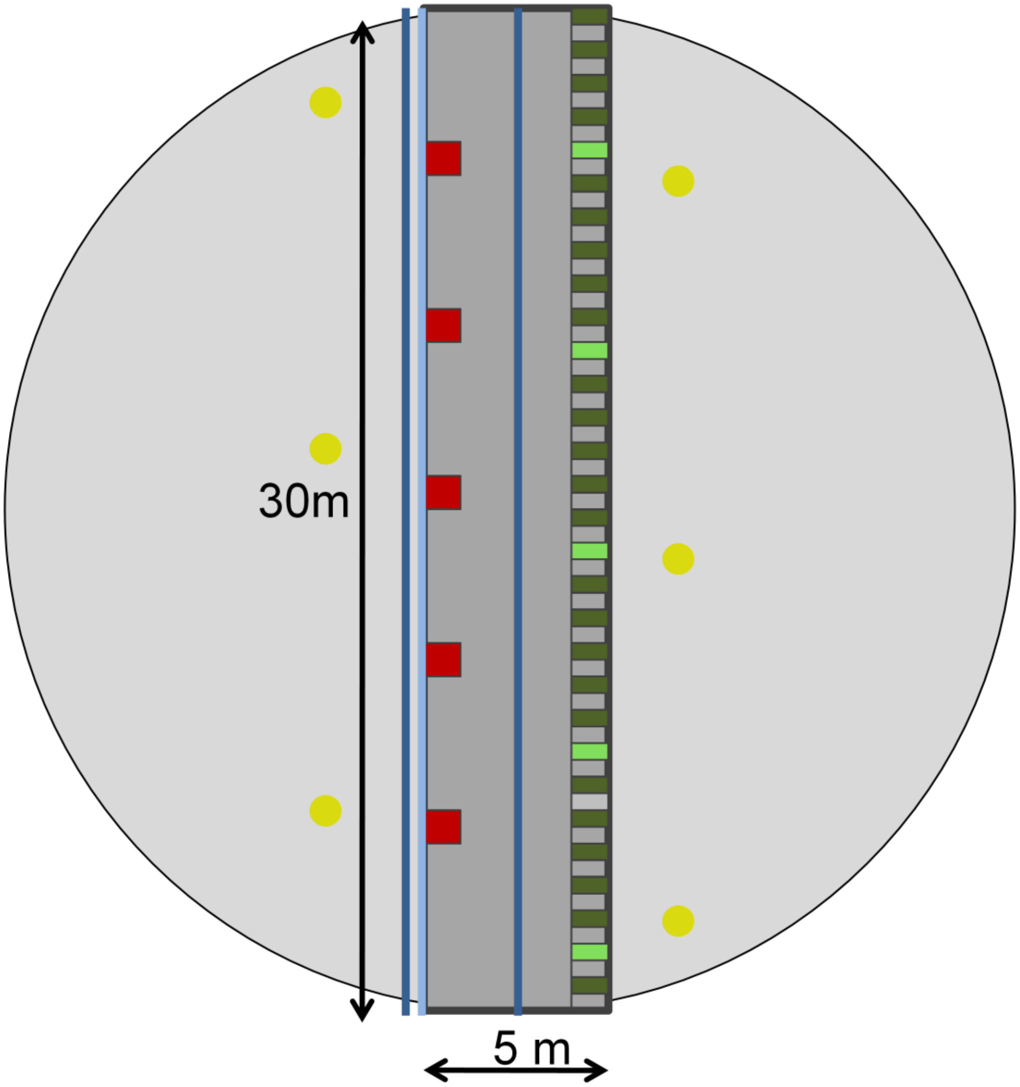


Figure 2. 5: Plot layout. The five by 30 m plot (dark gray) is nested in the Composite Burn Index (light gray). Soil samples were taken around the plot at the six yellow dots. Density and cover sampling occurred on the five-one m^2 subplots along the west boundary of the plot (red). Aboveground biomass samples were taken from five-one by 0.5 m subplots on the east boundary of the plot (light green) and were shifted one m each season (dark green). On plots containing oak, two shrub transects were used to measure shrub cover (dark blue). On PJ plots, a point transect along the west boundary was used as an additional measure of cover (light blue).

Figure 2. 6: A field crew calibrating density & cover measurements.

Figure 2. 7: Bags of biomass drying in the lab prior to oven drying and weighing.

Figure 2. 8: Soil corer with 10 cm of soil. Six cores were collected on each plot.

2.4 Statistical Methods

Due to non-normal data, a univariate PerMANOVA (a non-parametric distance based permutation ANOVA) with randomized complete blocks was used to obtain a paired design (PC-ORD 5.1) (McCune and Mefford 2006). The test was performed using Euclidian distance and as a randomized test with 4,999 runs. To determine differences in plant community compositions between treated and untreated plots, aboveground biomass data by species were ordinated using nonmetric multidimensional scaling (NMDS; PC-ORD 5.1) (McCune and Mefford 2006). This method is used for ecological data to reduce complex datasets to identify gradients, and is best suited for ecological data due to its inherent non-normal distribution and presence of many zeros (McCune et al. 2002a). To discover how the imazapic application affected native communities, non-native species were excluded from the ordinations, and native species aboveground biomass was grouped by year. To include plots with no data, an additional species column was added in which the number one was placed in each cell (Clarke et al. 2006). Ordinations were run with 500 iterations, random starting conditions, 50 runs and a stability criterion of 0.00001. Stress and instability were also recorded. Stress refers to the departure of the data as shown in an ordination figure from its location in the dissimilarity matrix. Lower stress indicates that the ordination figure is an accurate representation of the data. This number tends to increase as sample size and the number of species increases, however for ecological data stress below 20 is ideal, however it is still interpretable if under 30. Instability refers to whether further exploration of the data is necessary to obtain a better ordination output. Larger instability numbers indicate that a better figure may exist to explain the data. PerMANOVAs were used to test for differences in community composition between treated and untreated plots. Both the NMDS and multivariate PerMANOVAs used a Sorensen distance measure. Indicator species analyses were performed to discover whether any species were strongly correlated with either treatment (PC-ORD 5.1) (McCune and Mefford 2006). These tests were run with 4,999 randomizations and a species was considered an indicator species if it demonstrated a significant p-value ($p<0.05$) and had an indicator value greater than 25.

3 Results

3.1 Effects of Imazapic on Cheatgrass

During the 2008 sampling season cheatgrass was present on the PJ sites in limited quantities and was completely absent on the GO site. By the spring of 2009, isolated patches of cheatgrass were appearing on both the PJ and GO sites with the PJ site demonstrating significantly less cheatgrass on the treated plots than the untreated plots (Figure 3.1). By the spring of 2010 all treatment effects disappeared on the PJ site and the GO site demonstrated higher cheatgrass biomass on the treated plots than untreated plots, however differences were small and not significant (Figure 3.1).

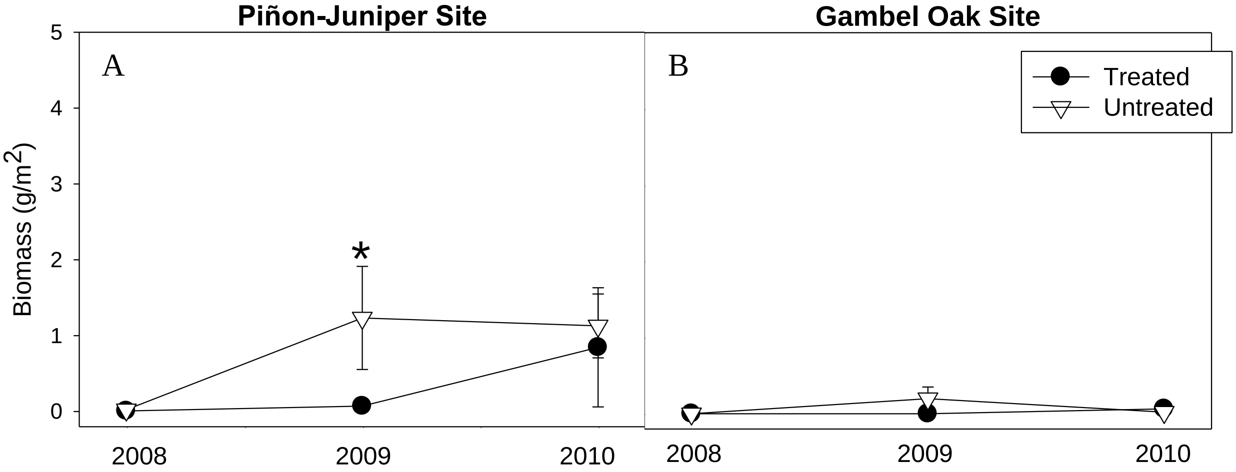


Figure 3. 1: Average (+ SE) aboveground biomass of cheatgrass (*Bromus tectorum*) on the **A**, PJ and **B**, GO sites in the springs of 2008, 2009 and 2010. Significantly different means ($p<0.05$) are indicated by an asterisk.

3.2 Effects of Imazapic on Non-native Species

Of all species identified in the study areas, only six species (4%) were non-natives, and included cheatgrass, prickly lettuce (*Lactuca serriola* L.), yellow salsify (*Tragopogon dubius* Scop.), common dandelion (*Taraxacum officinale* F.H. Wigg.), crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.), and prickly Russian thistle (*Salsola tragus* L.). Of the non-native species, the only predominant one was prickly lettuce, and was first detected on the plots during the spring of 2009. During this season the PJ site demonstrated almost ten times more prickly lettuce aboveground biomass on untreated plots than treated plots, while on the GO site there was no difference between the prickly lettuce aboveground biomass on the untreated and treated plots (Figure 3.2). Although statistical significance disappeared on the PJ site by the fall of 2009, trends still indicated there was almost twice as much prickly lettuce on untreated plots than treated plots (Figure 3.2). Furthermore, although the GO site still demonstrated a lack of statistical significance, by the fall of 2009, there was an average of thirty times more prickly lettuce on untreated plots than treated plots (Figure 3.2). By the spring of 2010 trends had switched with treated plots demonstrating more prickly lettuce biomass than untreated plots; however, no differences were significantly different (Figure 3.2). The density and aerial cover of prickly lettuce followed similar trends as the aboveground biomass (data not shown).

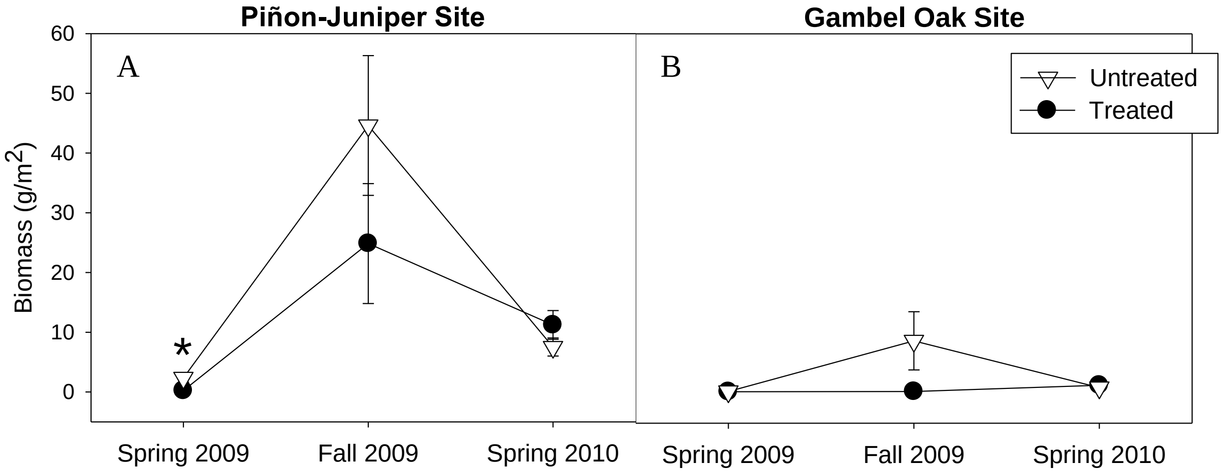


Figure 3. 2: Average (+ SE) aboveground biomass of prickly lettuce (*Lactuca serriola*) on the **A**, PJ and **B**, GO sites in the spring and fall of 2009 and spring of 2010. Prickly lettuce was first detected on the site in the spring of 2009. Significantly different means ($p<0.05$) are indicated by an asterisk.

3.3 Effects of Imazapic on Native Species

On the PJ site, 84 native species were identified through the duration of the study, consisting of 78% forbs, 10% grasses, and 12% shrubs. The most common forbs on this site were willowherb (*Epilobium brachycarpum* C. Presl.), longleaf phlox (*Phlox longifolia* Nutt.), and redroot buckwheat (*Eriogonum racemosum* Nutt.), while common grasses included Indian ricegrass (*Achnatherum hymenoides* (Roem. & Schult.) Barkworth), squirreltail (*Elymus elymoides* (Raf.) Swezey), and sixweeks fescue (*Vulpia octoflora* (Walter) Rydb.) and common shrubs included Gambel oak, toadflax penstemon and wild crab apple (*Peraphyllum ramosissimum* Nutt.). On the GO site, 77 native species were identified, consisting of 73% forbs, 10% grasses, and 17% shrubs. Common forb species on the GO site included longleaf phlox, Nuttall’s sunflower (*Helianthus nuttallii* Torr. & A. Gray), Bonneville pea (*Lathyrus brachycalyx* Rydb.) and redroot buckwheat, common grass species included muttongrass (*Poa fendleriana* (Steud.) Vasey) and slender wheatgrass (*Elymus trachycaulus* (Link) Gould ex Shinners), while common shrub species included Gambel oak, toadflax penstemon and mountain snowberry (*Symphoricarpos oreophilus* A. Gray).

3.3.1 Richness

Overall native species richness on the PJ site was statistically lower on treated plots than untreated plots during all five seasons sampled, and untreated plots ranged from having 25-80% more species than treated plots (Figure 3.3). On the GO site the richness of native species was statistically lower on treated plots during the spring 2008 and spring 2009 sampling seasons. However an overall trend of lower species richness on treated plots existed during all four seasons on the GO site, with untreated plots having 10-30% more species than the treated plots (Figure 3.3).

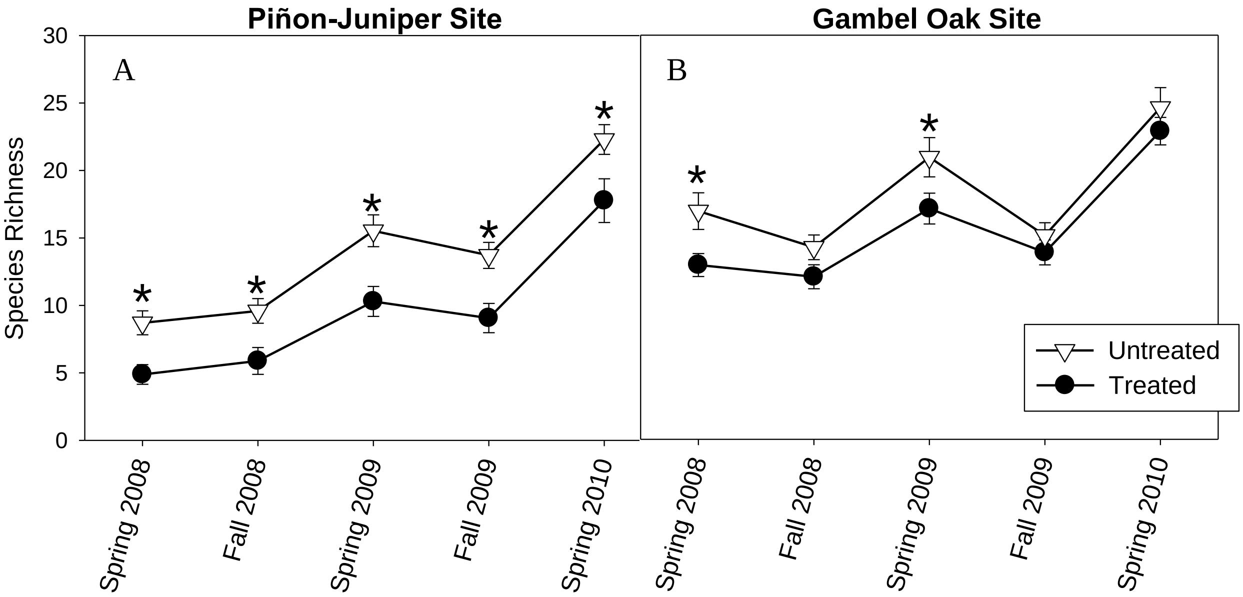


Figure 3. 3: Average (+ SE) species richness on the **A**, PJ and **B**, GO sites during all five seasons sampled. Significantly different treatment means ($p<0.05$) are indicated by an asterisk.

3.3.2 Herbaceous Biomass

To discover whether there was overall less herbaceous vegetation production on treated plots, the aboveground biomass of all native herbaceous species was grouped. On both the PJ site and the GO site there was less aboveground biomass on treated plots during all five seasons (Figure 3.4). On both sites, aboveground biomass demonstrated statistical significance in the spring 2008, spring 2009, and fall 2009 seasons. Aboveground biomass on untreated PJ plots ranged from being two to nine times higher than the aboveground biomass of native species on treated plots.

On the GO site, native species aboveground biomass on untreated plots ranged from being 1.5 to five times higher than that of treated plots. The density and aerial cover of native species on the PJ and GO sites followed the same trend of being higher on the untreated plots during all seasons sampled (data not shown).

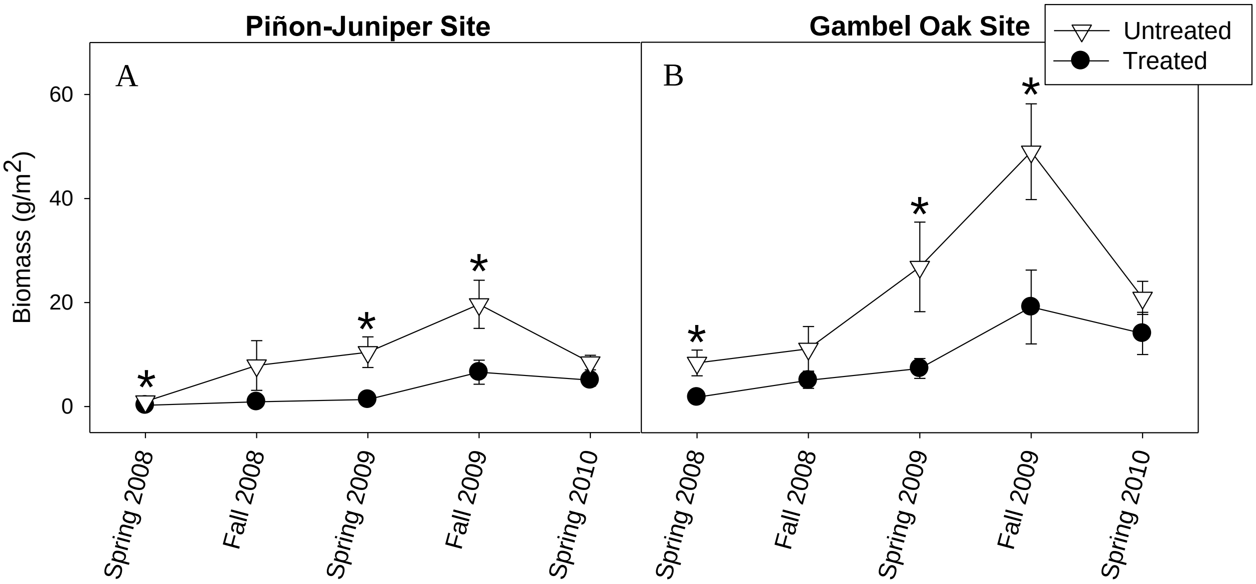


Figure 3. 4: Average (+ SE) aboveground native species biomass on the **A**, PJ and **B**, GO sites during all five seasons sampled. Significantly different treatment means ($p<0.05$) are indicated by an asterisk.

3.3.3 Life History Traits

The native herbaceous vegetation was grouped by annuals and perennials to discover whether either of these life histories was being differentially impacted by the herbicide application. Annuals on both the PJ and GO sites showed a trend of lower annual aboveground biomass on the treated plots (Figure 3.5). On the PJ site, the differences between aboveground biomass on untreated and treated plots were significant during the spring 2009 and fall 2009 seasons, while on the GO site the differences were significant during the spring 2008, spring 2009 and spring 2010 sampling seasons. Although most numbers were very small on both sites, on the PJ plots the aboveground biomass ranged from being two to 12 times higher on untreated plots than treated plots. On the GO site, the untreated plots had between two and 24 times more aboveground biomass than the untreated plots. Density and aerial cover followed the same trends as aboveground biomass (data not shown).

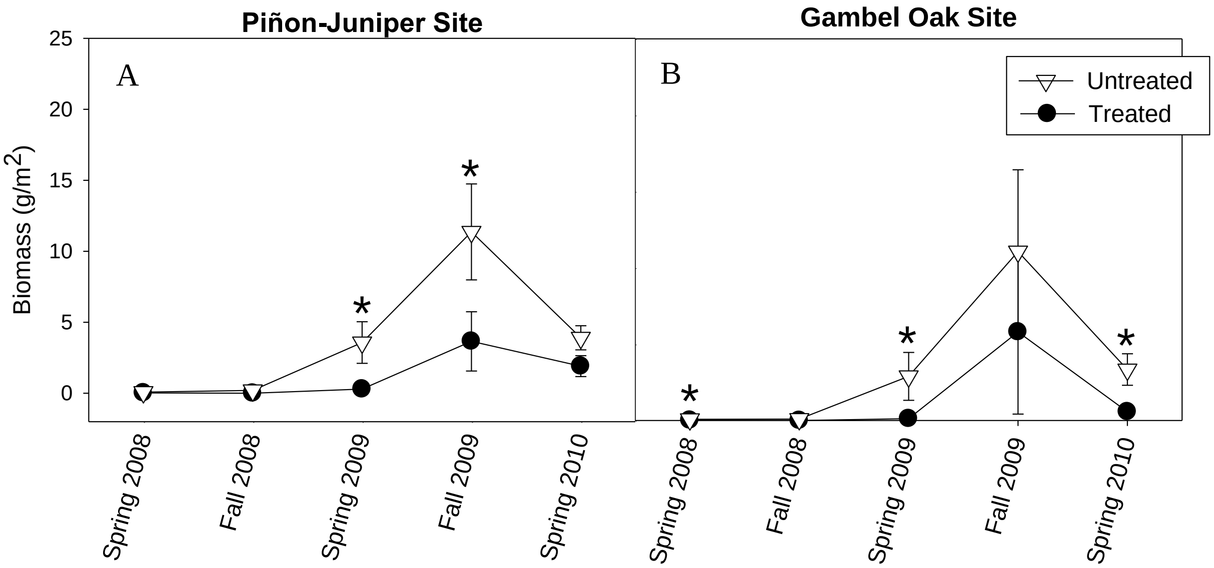


Figure 3. 5: Average (+ SE) aboveground biomass of native annual species on the **A**, PJ and **B**, GO sites during all five seasons sampled. Significantly different means ($p<0.05$) are indicated by an asterisk.

Perennial herbaceous species also demonstrated a trend of increased aboveground biomass on untreated plots as compared to the treated plots. On the PJ site, perennial aboveground biomass was significantly higher on untreated plots during the spring 2008 and spring 2009 seasons, while on the GO site, perennial aboveground biomass was significantly higher on untreated plots during the spring 2008, spring 2009 and fall 2009 sampling seasons (Figure 3.6). On the PJ site, untreated plots demonstrated between 1.5 and nine times more aboveground biomass than treated plots, while on the GO site, untreated plots had between 1.5 and five times more aboveground biomass than treated plots. Density and aerial cover followed the same trends as aboveground biomass (data not shown).

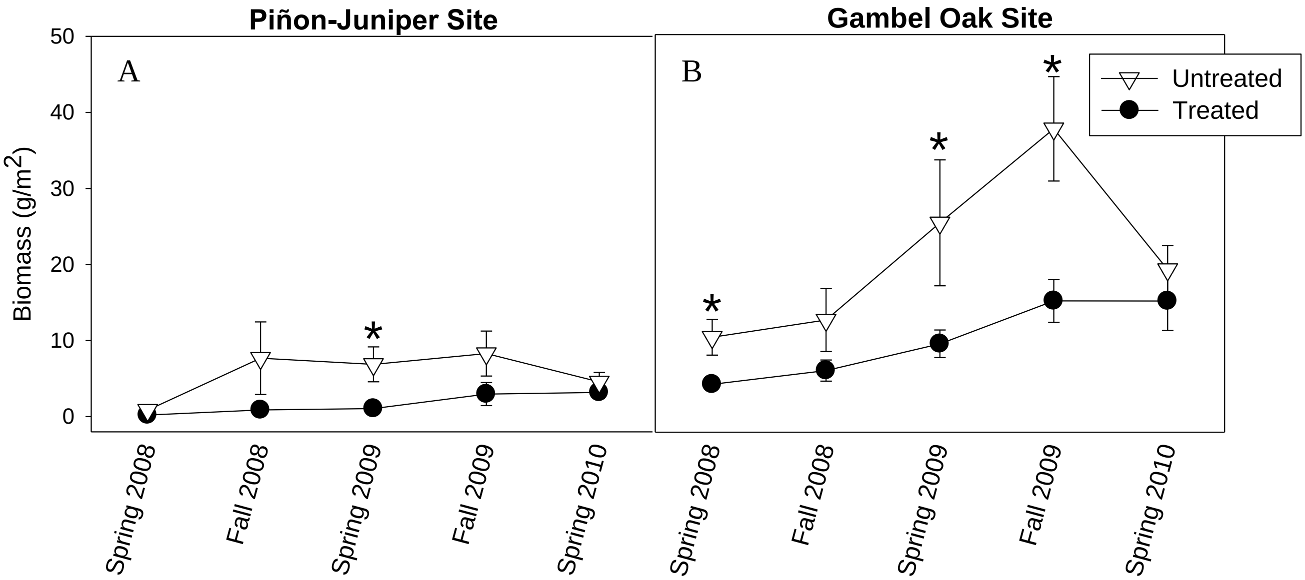


Figure 3. 6: Average (+ SE) aboveground biomass of native herbaceous perennial species on the **A**, PJ and **B**, GO sites during all five seasons sampled. Significantly different means ($p<0.05$) are indicated by an asterisk.

3.3.4 Shrubs

The overall plot-level aerial cover of Gambel oak was low on the PJ plots, ranging from 2.37% to 5.34% on the untreated plots and from 1.86% to 4.59% on the treated plots, with no statistical differences between the treatments (Figure 3.7). On the GO plots, aerial cover ranged from 5.28% to 35.93% on the untreated plots and from 5.63% to 36.22% on the treated plots (Table 2.9; Fig. 2.9). There were no significant differences between treatment types during any of the sampled seasons. The plot-scale shrub density (excluding Gambel oak) demonstrated a trend of more plants per plot on untreated plots on both the PJ and GO sites (Figure 3.8). On the PJ site, untreated plots had an average of 30-50% more shrubs than treated plots, however due to the large variation among plots, none of these differences were significant. The GO site, however, demonstrates significantly higher shrub density on untreated plots during the fall 2008, spring 2009 and fall 2009 seasons, with the untreated plots having 90-150% more shrubs than the treated plots.

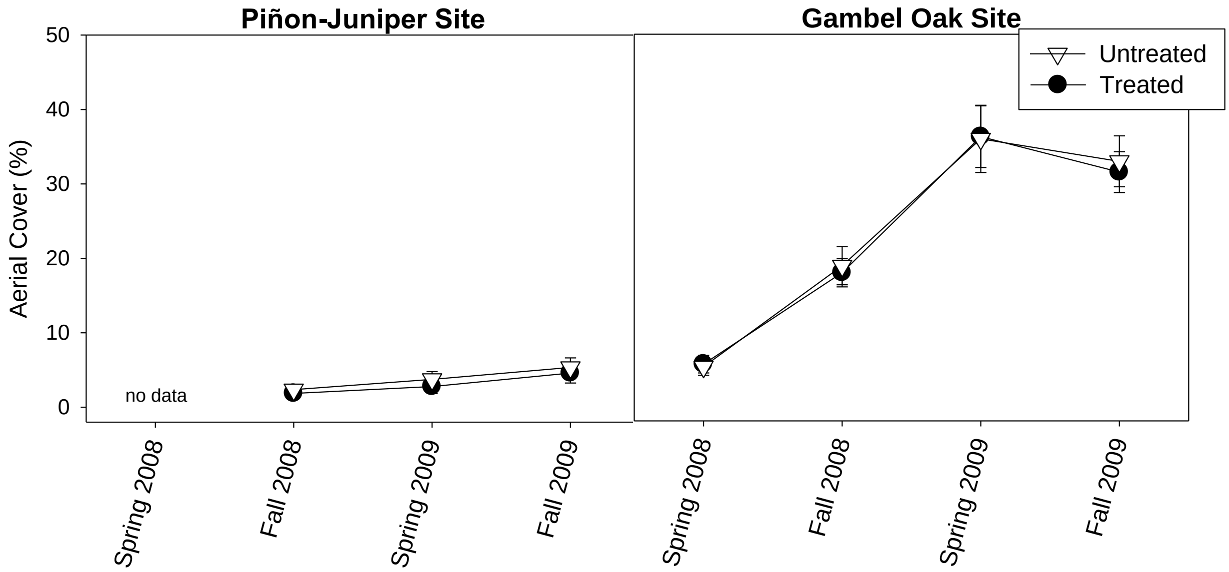


Figure 3. 7: Average (+ SE) plot-scale aerial cover of Gambel oak on the **A**, PJ and **B**, GO sites during the first four seasons sampled. No means are significantly different.

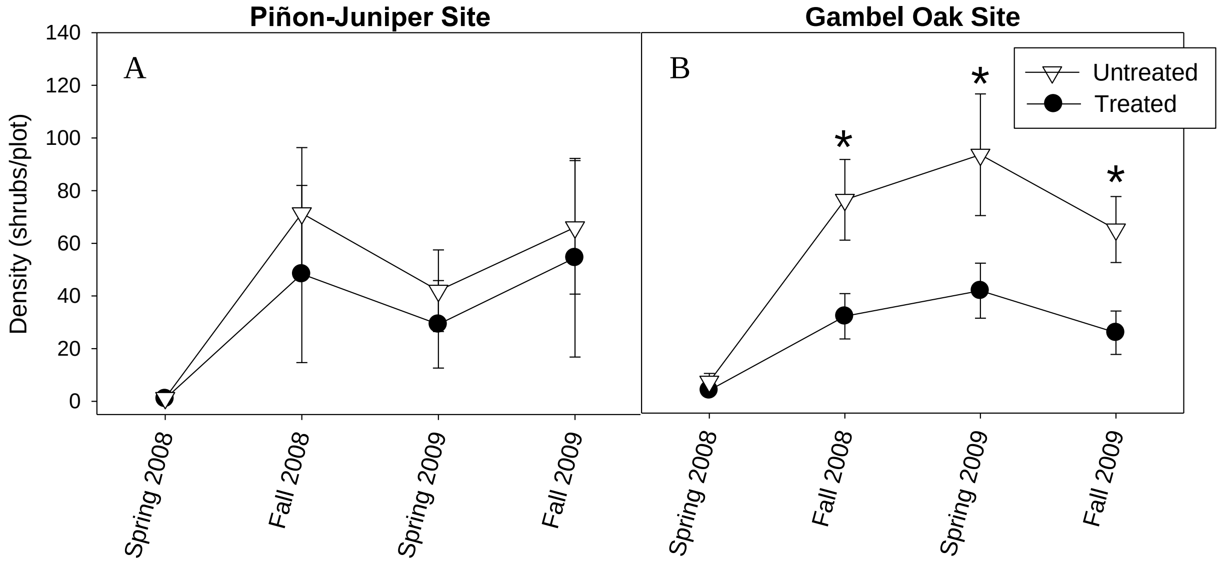


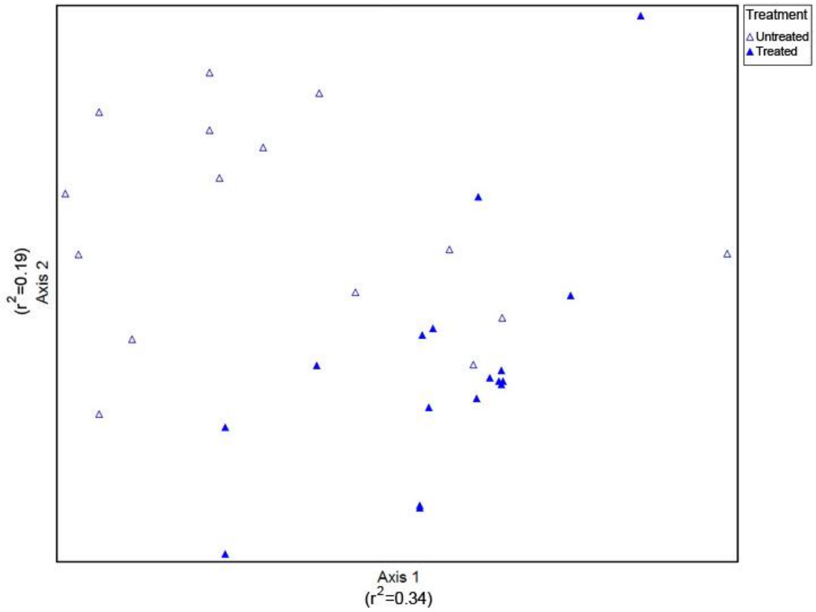
Figure 3. 8: Average (+ SE) plot-scale density of native shrubs (excluding Gambel oak) on the **A**, PJ and **B**, GO sites during the first four seasons sampled. Significantly different means ($p<0.05$) are indicated by an asterisk.

3.4 Community Analysis

In these ordinations, each open triangle represents an untreated plot, while each filled triangle represents a treated plot. Plots with similar species composition tend to be closer together in the ordination figures than those plots that are dissimilar. The visual differences between treated and untreated plots are indicated by the general separation of open and filled triangles in the ordination figures. On the PJ site, there was not enough aboveground biomass during 2008 for ordination outputs. In 2009, however, the ordination showed visual differences in species composition between the treatments. Furthermore, 2009 demonstrated significant differences in species composition between the treatments (p=0.0082). By 2010 the ordination did not show obvious visual differences in species composition between the treatments and there were no significant differences. On the GO site the ordinations showed visual differences in species compositions during both 2008 and 2009. These differences were significant in both years (p=0.0068 and 0.0238, respectively). By 2010, however, the ordination showed no visual differences in species composition and there were no significant differences between the treatments (Figures 3.9 and 3.10).

Figure 3. 9: NMDS ordination for PJ plots during **A**, 2009 and **B**, 2010. A, a two-dimensional solution was recommended with stress=21.57 and instability=0.00089. PerMANOVA indicates significantly different communities at p=0.0082 and $F_{(1,16)}$=2.7903. B, a three-dimensional solution was recommended with stress=15.23 and instability=0.00001. PerMANOVA indicates the communities were not significantly different.

(A)



(B)

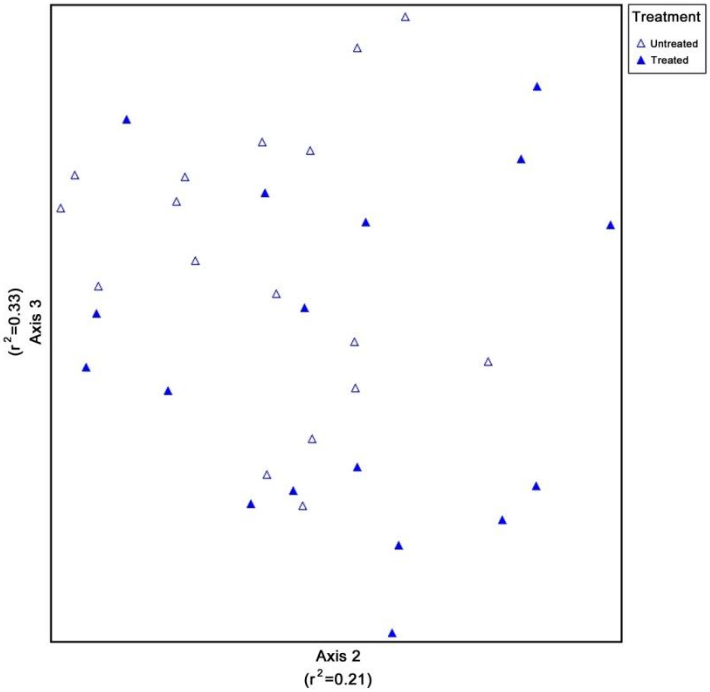
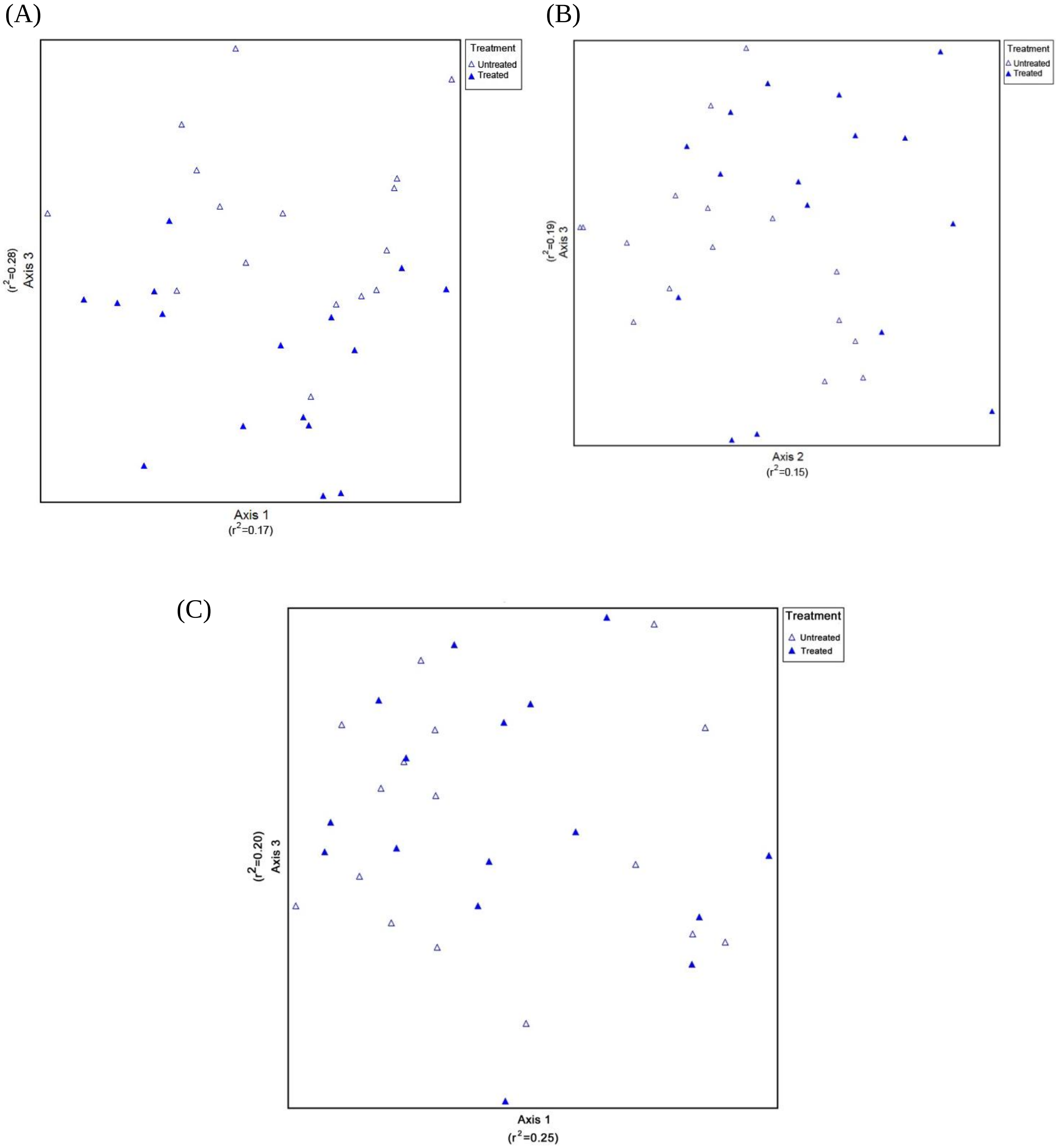


Figure 3. 10: NMDS ordinations for GO plots during **A**, 2008 **B**, 2009 and **C**, 2010. A, a three-dimensional solution was recommended with stress=16.46 and instability=0.00001. PerMANOVA indicates significantly different communities at p=0.0068 and $F_{(1,15)}$=2.2007. B, a three-dimensional solution was recommended with stress=17.26 and instability=0.00001. PerMANOVA indicates significantly different communities at p=0.0228 and $F_{(1,15)}$=1.7379. C, a three-dimensional solution was recommended with stress=16.90 and instability=0.00001. PerMANOVA indicates the communities were not significantly different.



A perfect indicator species would be one that is both always present in a specific treatment and is also exclusive to that treatment. Indicator species values are calculated using the relative abundance and relative frequency of a particular species in a particular treatment. If a species emerges as a strong indicator of a particular treatment, it is likely that this species will be found only in the treatment type and that it will be widespread throughout the treatment type. The PJ site had no indicator species during the first two sampling seasons (spring and fall 2008), however during the spring and fall 2009 and the spring 2010 sampling seasons there were species that were strongly correlated with the untreated plots (Table 2.11), while no species were indicators of treated plots. In the spring of 2009, indicator species of untreated plots included three small annual forbs, the fall 2009 had one annual forb and the spring 2010 had three perennial forbs. When an indicator species analysis was run on species grouped by their families, indicators of untreated plots in the spring 2009 season were Asteraceae and Onagraceae families, while in the fall of 2009 only Onagraceae was an indicator of untreated plots. In the spring of 2010 Alliaceae and Saxifragaceae were indicators of untreated plots. No shrubs were indicators of either treatment type. The GO site also had only indicator species associated with untreated plots. During the spring 2008 season three perennial forbs and one perennial grass were indicators of untreated plots, while in the fall 2008 season, one perennial shrub was an indicator of untreated plots. In the spring 2009 season one annual forb and three perennial forbs were indicators of untreated plots and the fall 2009 season included two annual forbs, one perennial forb and one perennial shrub associated with untreated plots. In the spring 2010 season there were two annual forbs. When species were grouped according to their families, Asteraceae and Lilaceae emerged as indicators of untreated plots in the spring of 2008, while only Onagraceae was associated with untreated plots in the spring of 2009 and both Onagraceae and Polygonaceae were indicators of untreated plots in the fall of 2009. In the spring of 2010 Onagraceae again emerged as an indicator of untreated plots.

Table 2. 2: Summary of indicator species analysis results for **A**, PJ and **B**, GO sites. Aboveground biomass was used to determine indicator values for herbaceous species and botanical family, while density was used to determine indicator values for shrubs. Only statistically significant ($p<0.05$) indicator species and families are shown. Indicator values are given for each season a species emerged as an indicator. All significant indicator species were indicators of untreated plots.

A

PJ								
Indicator Species/Family	Spring 08	Fall 08	Spring 09	Fall 09	Spring 10	Life History	Life Form	Nativity
Epilobium brachycarpum	-	-	64.4	-	-	Annual	Forb	Native
Microsteris gracilis	-	-	48.1	-	-	Annual	Forb	Native
Polygonum douglasii	-	-	29.4	-	-	Annual	Forb	Native
Gayophytum diffusum	-	-	-	64.7	-	Annual	Forb	Native
Allium acuminata	-	-	-	-	34.9	Perennial	Forb	Native
Erigeron divergens	-	-	-	-	29.4	Perennail	Forb	Native
Lithophrama tenellum	-	-	-	-	34.5	Perennial	Forb	Native
Asteraceae	-	-	63.4	-	-	-	-	-
Onagraceae	-	-	64.4	70.4	-	-	-	-
Alliaceae	-	-	-	-	34.9	-	-	-
Saxifragaceae	-	-	-	-	34.5	-	-	-

B

	GO							
Indicator Species/Family	Spring 08	Fall 08	Spring 09	Fall 09	Spring 10	Life History	Life Form	Nativity
Calochortus flexuosus	42.9	-	-	-	-	Perennial	Forb	Native
Crepis occidentalis	30.7	-	-	-	-	Perennial	Forb	Native
Helianthus nuttallii	48.3	-	58.4	-	-	Perennial	Forb	Native
Poa fendleriana	53.6	-	-	-	-	Perennial	Grass	Native
Penstemon linarioides	-	66.4	-	60.8	-	Perennial	Shrub	Native
Epilobium brachycarpum	-	-	66.7	47.3	76.9	Annual	Forb	Native
Phlox longifolia	-	-	58.6	-	-	Perennial	Forb	Native
Zigadenus paniculatus	-	-	53.1	-	-	Perennial	Forb	Native
Heliomeris multiflora	-	-	-	55.9	-	Perennial	Forb	Native
Polygonum douglasii	-	-	-	52.8	48.8	Annual	Forb	Native
Asteraceae	78.3	-	-	-	-	-	-	-
Lilaceae	75.2	-	-	-	-	-	-	-
Onagraceae	-	-	60.5	60.5	78.1	-	-	-
Polygonaceae	-	-	-	52.2	-	-	-	-

4 Discussion

4.1 Effects of Imazapic on Non-Native Species

The north-east corner of Zion National Park has no roads or trails and accessibility is very difficult. For this reason, prior to the Dakota Hill Complex Fires, there was very little information on the amount of cheatgrass present in the area. The decision to apply imazapic herbicide post-fire was based on a pre-fire vegetation survey which indicated that there were at least trace amounts of cheatgrass present at four survey points in the East Fire, while cheatgrass was absent at 16 of the survey points in the East Fire. Morrow and Stahlman (1984) note that once introduced, cheatgrass can dominate a disturbed area within as little as five years, therefore Zion National Park employees felt that a proactive approach to managing cheatgrass in this area was necessary. However, due to the presumably low pre-fire cheatgrass numbers and the high intensity fire, cheatgrass has been very slow to invade the area and was not present on the study plots in high enough quantities to determine statistically valid treatment effects over the 2.5 years of this study. It is important to note, however, that as of spring 2010, cheatgrass demonstrated a strong recovery in the treated pinon-juniper plots, and on the Gambel oak plots there was more cheatgrass on treated plots than untreated plots, though insignificantly so.

There was only one predominant non-native species other than cheatgrass. Prickly lettuce, an invasive annual forb, first appeared on the site in the spring of 2009 (Figure 4.1). From our results, it appears that imazapic reduces the aboveground biomass of this quickly growing annual/biennial forb for up to two years, however as of the spring of 2010 there was more prickly lettuce on treated plots than untreated plots, though 2010 differences were not significant. The prickly lettuce on the GO plots followed the same trend, however there were no significant differences between the aboveground biomass on untreated and treated plots during any season.

Figure 4. 1: Mats of prickly lettuce (*Lactuca serriola*) found throughout the burned piñon-juniper woodlands.

4.2 Effects of Imazapic on Native Species

4.2.1 Richness

Our hypothesis that average native species richness would be initially lower on the treated plots, but that species richness would recover as time since herbicide application increased was partially supported, as it was initially lower, but has not yet demonstrated the expected recovery 2.5 years post treatment. On the PJ site, average richness was significantly lower on treated plots during all five seasons, and the trend does not appear to be fading as of the spring 2010 sampling season. The GO site also demonstrated the trend of lowered species richness on treated plots as compared to the untreated plots, but this trend disappeared by the fall 2009 sampling season. On the PJ plots, the large differences in species richness between the untreated and treated plots may be due to the herbicide still being active in the system as of spring 2010 and was still impacting the vegetation. According to Greg Cox (personal communication, Sept. 2007) of UAP Distribution, Inc., the herbicide could be expected to remain active in the soil for up to two or three years depending on the soil and precipitation characteristics of the site. However according to Tu et al. (2004), the average half-life of imazapic is 120 days in soil, which after 2.5 years would leave a negligible amount of herbicide in the soil. Kyser et al. (2007), however, speculated that cooler soils of the Intermountain West could result in the slower breakdown of imazapic, which could indicate that there was still more herbicide than expected in the soil. Alternatively, the herbicide was no longer active in the soil and the difference seen between untreated and treated plots on the PJ site could be a relic of the herbicide and the fact that the seeds of sensitive species had not yet been able to establish in the treated plots. As the differences between untreated and treated plots had almost disappeared on the GO site, it is possible that the imazapic was no longer active in this system. The vegetation communities on the PJ and GO site tend to be composed of a core of different species, and it is also possible that those on the GO site were not as sensitive to imazapic, or that they reacted through a stunting of growth or the presence of fewer individuals. Furthermore, the two sites were on different parent materials, and the GO plots tended to be on steep slopes which were more susceptible to herbicide depletion through erosion by water and wind. Gennari et al. (1998) stressed that the performance of imidazolinone herbicides is improved with high organic matter content and low soil pH values. Although these sites are on different parent materials, their organic matter contents are both approximately 3.5% and both sites have pH values averaging 7.5, a finding which supports the theory of differing species assemblages or differing topography causing the contradicting trends on the two sites.

4.2.2 Herbaceous Species Biomass

Similar to the findings of overall lower species richness, our hypothesis that the treated plots would initially have lower overall plant aboveground biomass but would recover by the second year after treatment was partially supported, as aboveground biomass on treated plots was lower, and by spring 2010 the treated area does appear to be converging with the untreated areas, however this result may be a relic of the late snow melt, and the resulting early developmental stages of the plants as of the spring 2010 sampling. Both the PJ and GO sites had higher aboveground biomass of native herbaceous species on the untreated plots through all five seasons of the study. Furthermore, these differences between untreated and treated plots appear to be increasing as time since fire and herbicide application increases (except for spring 2010 which was sampled early). Total aboveground biomass on untreated plots increased steadily through the four seasons of the study (again except for the spring 2010 season), while on the treated plots the aboveground biomass was lower. After spring of 2009 the aboveground biomass on treated plots increased much faster than previous seasons, which indicates that the herbicide may have degraded past a threshold for many native species approximately 1.5 years post-treatment. Furthermore, there was a lack of monsoonal activity during this time and precipitation was only 11% of average, indicating that it was likely due to herbicide degredation, not environmental factors, that caused this increase in aboveground biomass on treated plots. This finding is consistent with multiple studies that have indicated that imazapic reduces biomass and densities of native species when there is no weed interference (Beran et al. 1999a; Beran et al. 1999b).

4.2.3 Life History Traits

Our hypothesis that native annuals would be adversely affected by the imazapic application more than perennials was again partially supported, as findings indicate that aboveground biomass of both annuals and perennials was significantly reduced on treated plots. When looking at only native annuals, similar results are seen as those of all native herbaceous species. On both the PJ and GO sites, annuals on untreated plots began establishing at high rates by the spring of 2009, however as of this time, the annuals on treated plots still appear suppressed by the herbicide. It was not until the fall of 2009 when annual establishment increased on treated plots, a full season after the aboveground biomass began to increase on the untreated plots. This discrepancy between untreated and treated plots is highly evident on the PJ site; the trend is weaker on the GO site. Although the aboveground biomass of native annuals began to show a recovery on treated plots by the fall of 2009, the density of annuals was still low in the fall 2009 sampling season, while there were steep increases in the untreated plots by the spring of 2009. By spring 2010 there were still more annuals on untreated plots, with the differences on the GO site being significant. There was an overall decrease in annuals in both treatment types and on both sites during this season, however, which is likely the result of the late snowmelt and resulting delayed plant growth in relation to the field season timing.

According to Vollmer and Vollmer (2008), perennials tend to be more resistant to imazapic, since it targets green and growing tissue. However in a post-fire application where all the above-ground parts of herbaceous perennial plants were killed in the fire, it is possible that the herbicide affects the perennials just as much as annuals due to the fact that the perennials do not have any established above-ground living tissue from previous seasons. Perennials on untreated plots quickly established within the first year post-fire. However, on the treated plots, the growth of perennials remained suppressed until the fall 2009 season in PJ and the spring 2009 in GO, when the rate of aboveground biomass accumulation began increasing. However as with annuals, the rate of recovery of perennials on treated plots was not as high as those on untreated plots. By the spring of 2010, the aboveground biomass of herbaceous perennials in treated and untreated areas appeared to be converging, however due to early sampling it is difficult to know whether this trend will continue. In general the density of perennials on untreated plots did not outnumber those on treated plots. This indicates that although there may not have been fewer perennials on treated plots, those that did establish were smaller and perhaps less vigorous in the herbicide treated plots.

4.2.4 Shrubs

Our hypothesis that shrubs would be initially stunted, but would quickly recover was partially supported as Gambel oak was found to be unaffected but other shrub species have demonstrated affects lasting at least two years attributable to the imazapic application. Since Gambel oak shrublands make up a considerable portion of the Park and are very important to wildlife, this species was of utmost management concern to Zion National Park staff in regards to this application of imazapic. Gambel oak was present on both the PJ and GO sites, and neither site showed any evidence of reduced cover in this species. The slight reduction in the cover of Gambel oak during the 2009 sampling season was likely due to the lack of summer moisture and the resultant early drying and falling of the leaves. It is possible that the extensive underground root systems characteristic of Gambel oak (Tiedemann et al. 1987) allowed this shrub to be resistant to the herbicide application. Although studies have demonstrated that shrubs generally do not suffer long term reductions in cover and flowering stem densities from imazapic (Eddington 2006; Vollmer and Vollmer 2008), shrub species other than Gambel oak appeared affected, with some seasons demonstrating treated plot averages as little as half the density of untreated plots. Although some differences were large on the PJ plots, none were significant and the difference between treated and untreated plots appears to be decreasing as time since herbicide application increases. This finding is in partial agreement with Vollmer and Vollmer (2008) who found that some shrub species had initial reductions in cover, but recovered within one year of the treatment. On the GO site, however, the differences in shrub density between untreated and treated plots were significant for three of the four seasons sampled. This finding is not widely found in the literature and may be unprecedented. Again, this imazapic application to the post-fire environment where all above-ground parts of perennial plants are killed supports this idea.

4.3 Community Analysis

Analysis of the herbaceous understory plant community through NMDS indicates that the application of imazapic resulted in overall different community compositions since a visual separation between treated and untreated plots is discernable in all ordinations from 2008 and 2009. This indicates that the communities may be on different trajectories of post-fire recovery, however long term data collection would be necessary to fully understand the dynamics of the communities' recovery following the imazapic herbicide application. PerMANOVAs for both sites during the 2008 and 2009 seasons demonstrated significant differences between understory plant communities on untreated and treated plots. By spring 2010 both sites demonstrated no visual discernable differences in the ordinations, and treated and untreated communities were no longer significantly different from each other when tested through PerMANOVAs. This could be a result of the early sampling in the spring of 2010 or could indicate that the treated communities are capable of recovering once the herbicide had diminished from the system.

Although most of the native species on both sites appeared to demonstrate some sort of adverse effects from the herbicide, such as stunting, some species and plant families emerged as strong indicators of untreated plots. No species present in this study emerged as indicators of treated plots, which implies that the herbicide did not assist the establishment of any native species. This trend is of concern since many of the indicator species of untreated plots were also those found to be most common on the sites. On the PJ site, the annual forb willowherb was the only common indicator species, however as it was also the most common species on the PJ site. This finding could suggest that there may be a disproportionate effect due to the reduction in aboveground biomass of this species. On the GO site, four of the most common species on the site emerged as indicator species. Longleaf phlox and Nuttall's sunflower were two of the most common forbs on the site, while muttongrass was the most common grass, and toadflax penstemon was one of the most common shrubs. Since almost half of the most common species on the GO site emerged as indicators of untreated plots, the treated plots could have suffered disproportionately from the imazapic herbicide application. Furthermore, on the PJ site, the Asteraceae, Onagraceae, Alliaceae and Saxifragaceae families emerged as indicator familes, while on the GO site, the Asteraceae, Lilaceae, Onagraceae, and Polygonaceae families emerged as indicator families. This finding is in partial discord with Barnes (2007) who found that species in the Asteraceae family were tolerant to applications of imazapic herbicide.

5 Management Implications

The findings of this research are imperative to future management decisions since imazapic herbicide has not been widely used at large-scales post-fire. It must be noted that these sites may not be exemplary of most due to the limited pre-fire cheatgrass presence, and in this case the threat of cheatgrass invasion may have been smaller than the damage to the native species by the imazapic herbicide. However, this research indicates that when applied post-fire as a pre-emergent herbicide, imazapic reduces the aboveground biomass, density and aerial cover of many native species, likely because after high severity fire all annual and perennial herbaceous species must start from seed. This research further indicates that regardless of whether the imazapic was still active in the soil 2.5 years post-application, there were still deviations between the untreated and treated plots. The species that tended to be most affected covered all life histories and life forms and ranged from annual forbs and grasses, to perennial forbs and shrubs. Furthermore, in this ecosystem, some of the most common species were also the ones that were most affected by the herbicide, potentially resulting in greater impacts to the overall vegetation community on treated plots. The differences in community composition further indicate that the application of imazapic may have set the communities on different successional trajectories; however, results suggest that the communities may be converging. Long-term research on these sites would be necessary to fully understand the long-term consequences of the imazapic herbicide application.

The reductions in overall vegetation can create more open growing space for species to establish. Unfortunately, if cheatgrass is present, it is possible that the overall lack of complete control demonstrated by other studies (Baker et al. 2009; Matchett et al. 2009b) coupled with the delayed recovery of native species in treated areas could allow this quickly establishing invasive grass a further advantage over native species. Although other studies have indicated that burning prior to the use of imazapic herbicides provides better control of cheatgrass (Matchett et al. 2009b), it also appears to reduce the richness, aboveground biomass, density and aerial cover of native species. Establishment of these native species is essential to maintain fire regimes within the historical range of variability for this ecosystem and thereby achieve long term cheatgrass control; however this imazapic treatment may make the successful establishment of native species very difficult. Therefore a sequence of burning and imazapic herbicide may not be enough to control cheatgrass and restore native habitats, and other methods must be considered, either alone or in conjunction with burning and imazapic herbicide.

Study 2:

Effects of a Post-Fire Imazapic Herbicide Application on Cheatgrass Germination in Zion National Park, Utah

Abstract

Cheatgrass (*Bromus tectorum* L.) is an invasive annual grass that quickly dominates disturbed areas and is responsible for reduced richness and diversity of native plant communities. Although many control methods have been attempted, no one method has yet proven successful, thus some studies have turned towards the use of herbicides such as imazapic (tradename Plateau®). During the summer of 2006 the Kolob Fire burned in the southwest corner Zion National Park. In response to the fire, a Burned Area Emergency Response (BAER) team recommended a landscape-scale application of imazapic herbicide to reduce cheatgrass occurrence in the Park. The implications of such a large-scale application of imazapic herbicide to a burned landscape are not fully understood. Therefore the germination of cheatgrass 0.5 years and 2.5 years post-application was assessed, as the treatment could be considered ineffective if the aboveground biomass and density of cheatgrass plants were reduced but the seed production and viability remained constant. The monitoring was conducted using a paired plot study (treated and untreated) in a piñon-juniper (*Pinus monophylla* Torr. & Frém.- *Juniperus osteosperma* (Torr.) Little) woodland. The germination study indicated that there was little change in germination potential between cheatgrass plants on treated and untreated plots. This finding suggests that the imazapic herbicide application has little effect on the ability of cheatgrass that survives the application to reproduce and colonize the site.

1 Introduction

Each year, Americans spend billions of dollars in the attempt to control invasive plants (Pimentel et al. 2005). These invasive plants can cause alterations in plant community compositions and biodiversity, which can affect insect and animal communities, alter nutrient and water cycles, and modify disturbance regimes such as fires (Mooney and Cleland 2001; Vitousek 1990; Young and Evans 1978). Cheatgrass (*Bromus tectorum* L.) is an invasive plant of particular concern. Introduced to North America in the late 1800s, cheatgrass has since spread to occupy over 40 million ha across the West (Mack 1981). Once introduced, cheatgrass can dominate a disturbed area within only five years (Morrow and Stahlman 1984) and in western North America is responsible for reduced richness and diversity of native plant communities (Monsen 1992) making this invasive annual grass of utmost management concern. Cheatgrass demonstrates extremely high germination rates with almost 100 percent germination in fully ripened seeds (Allen et al. 1994; Beckstead et al. 1996; Hull and Hansen 1974; Meyer and Allen 1999), and when conditions are favorable, it can germinate in as little as four to six days (Frasier 1992). Cheatgrass is a self-pollinating species, which helps contribute to its high germination rates (Meyer and Allen 1999), and although initially dormant, cheatgrass seeds lose their dormancy during dry summer conditions (Beckstead et al. 1996) and germinate in response to fall, winter, and early spring precipitation (Hulbert 1955; Klemmedson 1964; Stewart and Hull 1949). Many methods for controlling cheatgrass have been attempted; however due to its high germination rates and ability to germinate throughout the fall, winter, and spring months, no one method has proven successful.

Recently, some studies have turned to the use of herbicides to control cheatgrass, and one chemical that has shown recent promise in slowing or eliminating the spread of cheatgrass is imazapic. According to Masters et al. (1996), the Imidazolinone herbicide family (to which imazapic belongs) is a promising group of herbicides because several native annual and perennial grasses and forbs are tolerant. Since cheatgrass seeds demonstrate dormancy, and therefore germinate throughout the growing season (Mack and Pyke 1983), an herbicide must remain active in the soil for at least one growing season, thereby killing the seedlings as they emerge, to obtain successful control (Young and Clements 2000). This herbicide works through the active ingredient binding to a plant enzyme that then inhibits the production of essential amino acids that are necessary for plants to add new tissue (Vollmer and Vollmer 2008), and is often used as a pre-emergent herbicide. Although many studies have been conducted on the efficacy of this herbicide on first generation cheatgrass plants, no studies have yet confronted the issue of whether plants that do survive the treatment can successfully reproduce. Furthermore, there is no research on the effects of stress on the production of viable cheatgrass seeds. If some cheatgrass plants are capable of surviving the treatment and are able to reproduce at adequate rates to expand the population, then the herbicide application may not be worthwhile. Land managers, however, are beginning to use this herbicide over large areas without fully understanding the consequences.

One vegetation type of concern is piñon-juniper (*Pinus spp. - Juniperus spp.*) woodlands, which cover 20-30 million ha in the western US (West 1999). In southern Utah, these habitats are dominated by single leaf piñon (*P. monophylla* Torr. & Frem), two leaf piñon (*P. edulis* Englem.) and Utah juniper (*J. osteosperma* (Torr.) Little; (West 1999), and is the most common vegetation type in this region (Harper et al. 2003). Piñon pine and juniper species are valuable to wildlife for sustenance and habitat, while they are valuable to humans for fuel wood, piñon nuts and fence posts (Balda and Masters 1980). Prior to Euro-American settlement, infrequent, high intensity crown fires were natural in piñon-juniper woodlands similar to those in southern Utah, where it historically took several centuries for fuels to build up to fire-sustaining levels (Baker and Shinneman 2004; Floyd et al. 2000; Romme et al. 2008). These long fire return intervals can be attributed to the lack of horizontal continuity of fuels found in this system, where continuous grasses and herbaceous cover are uncommon. Instead, these woodlands tend to be dominated by widely spaced bunchgrasses, shrubs and trees (Floyd et al. 2000). These discontinuous fuels also create a patchy environment in which fires only spread through a large area under extreme conditions (Bruner and Klebenow 1979). However when burned, the bare soil and open growing spaces can allow for ease of cheatgrass invasion (Harper et al. 2003) due to the removal of established perennial plants and the ability of quickly establishing cheatgrass to utilize available resources before native plants can effectively reestablish on the site (Melgoza and Nowak 1991). By adding early summer fuels, and a component of standing fine, dead and dry fuels that can last for years in semiarid habitats, cheatgrass changes fire regimes by extending the fire season both earlier and later in the year and resulting in more frequent fires (Brooks et al. 2004; Klemmedson 1964; Knapp 1996; Ziska et al. 2005). This potential invasion could lead to an annual dominated system that would likely never return to a shrubland or piñon-juniper woodland (Erdman 1970).

In late June of 2006, the Kolob Fire burned over 4,200 ha in the southwest part of Zion National Park, Utah. A large proportion of this fire was in the piñon-juniper woodland vegetation type and was dominated by cheatgrass prior to the fire. A Burned Area Emergency Response (BAER) team assessed the impacts of the fires and made management decisions based on the threat of post-fire cheatgrass invasion. Imazapic herbicide was applied in late October through early November of 2006. Approximately 3,500 ha were treated with the herbicide.

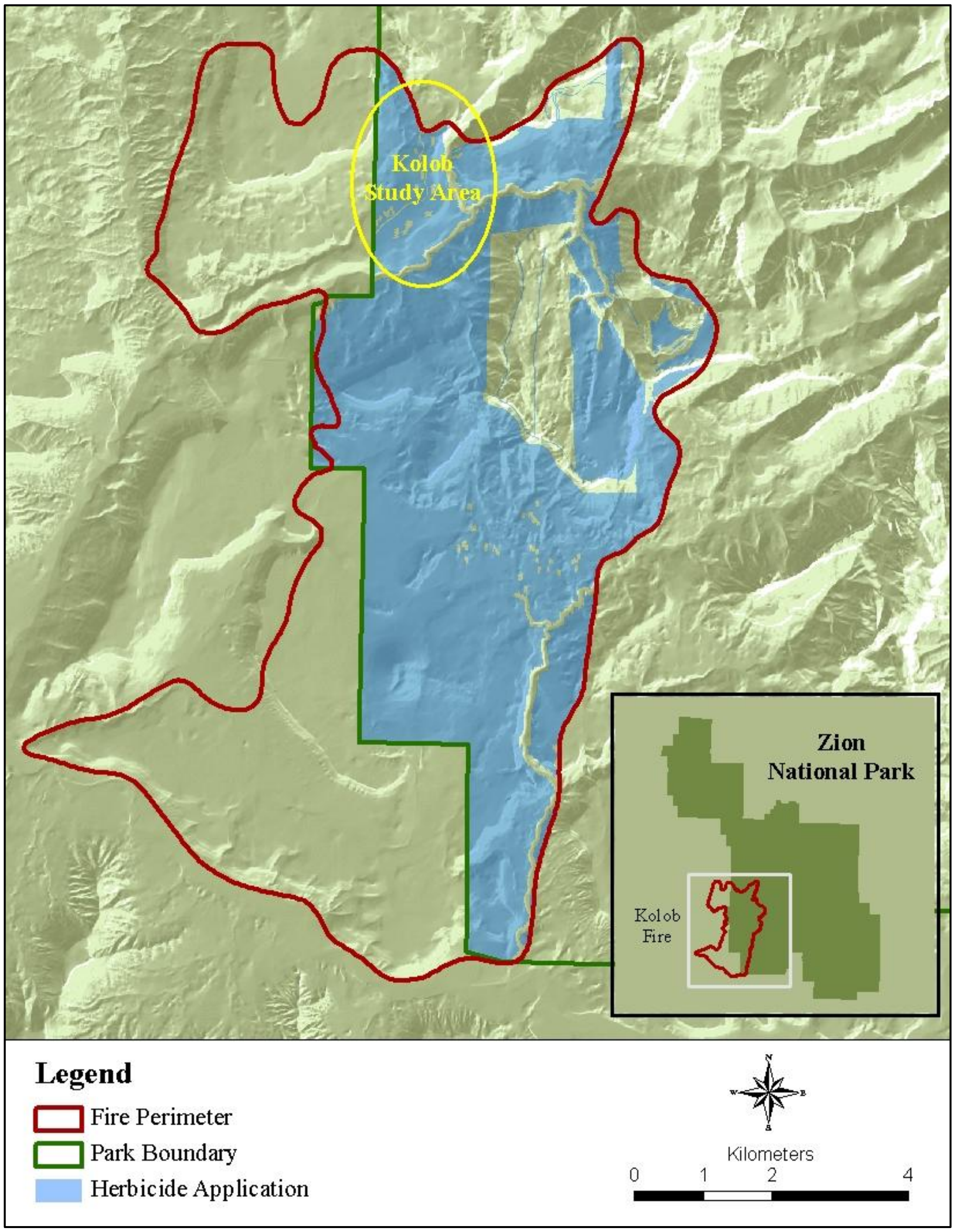


Figure 1. 1: Treatment and study area. The fire perimeter is shown in red, while the 3,500 burned ha that received an aerial application of imazapic herbicide are shown in blue. The yellow circle represents the vicinity of the study area.

1.1 Objectives & Hypotheses

The general objective of this project was:

1. To discover whether the imazapic herbicide application was effective at reducing the germination rate of cheatgrass plants that were able to survive the treatment.

We tested the following hypothesis:

1. Cheatgrass plants stressed by the herbicide application will result in plants demonstrating lower germination rates than those present in untreated areas.

2 Methods

2.1 Study Area

This study is located on the northern portion of the Kolob Fire (Fig. 3.1) in an area that experiences high recreation use. The imazapic herbicide was applied to the burned area within Zion National Park by helicopter at a rate of 584 ml per ha (eight oz per acre) in late October through early November of 2006. Due to timelines associated with the National Environmental Policy Act, there was a delay in the herbicide application and cheatgrass had begun to emerge prior to the treatment. The thirty-year average precipitation for the site is 39 cm, with the precipitation falling bimodally—during the winter as snow, and the summer as monsoonal precipitation. Monsoonal precipitation in the study area is unreliable. For the study years the annual precipitation for the study area was approximately 20% lower than average, however monsoonal precipitation in 2006 (which influenced the cheatgrass present in the spring 2007 sampling season) was 24% above average, while the monsoonal precipitation in 2008 (which influenced the cheatgrass present in the spring of 2009) was 40% below average (Figure 2.1). The average annual temperature for this area is 16.2^{o}C with both 2007 and 2008 being warmer than average (Figure 2.2).

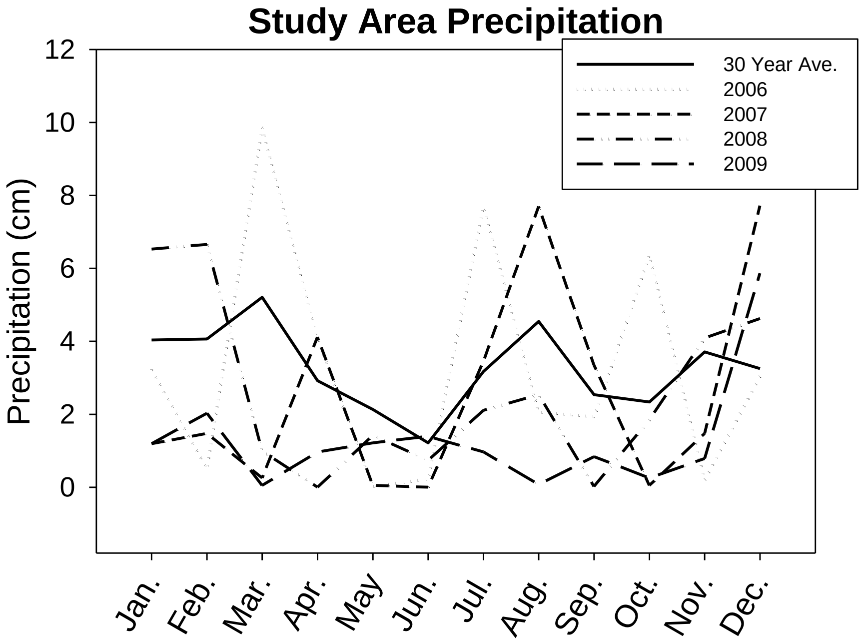


Figure 2. 1: Summary of study area precipitation from 2007-2010 in relation to the 30 year average.

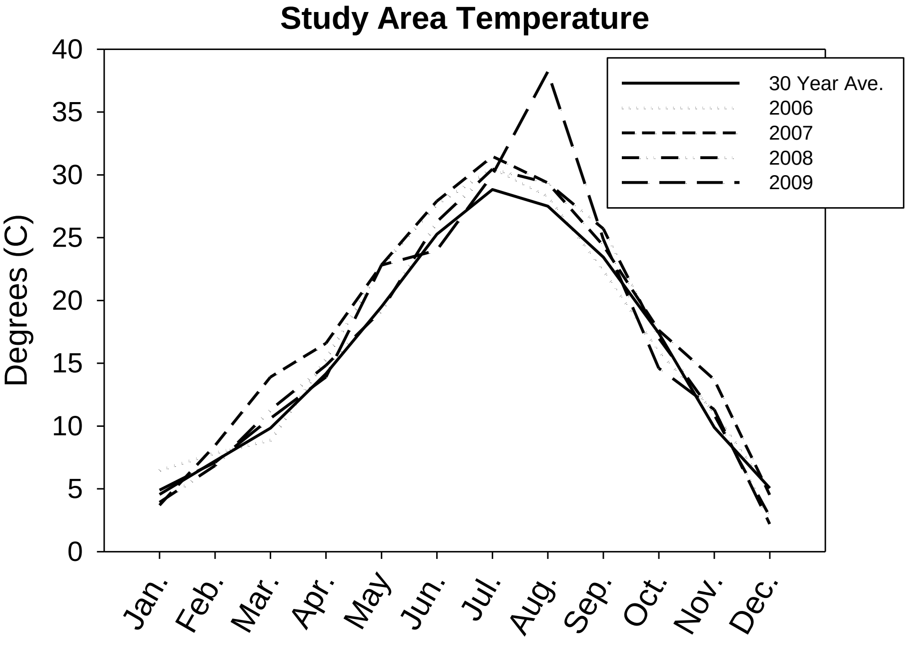


Figure 2. 1: Summary of study area temperature from 2007-2010 in relation to the 30 year average.

2.2 Study Design

The Kolob Terrace burned area was stratified by burn severity and parent material. The study site was located within a high and moderate severity burned piñon-juniper woodland. Burn severity was initially assessed by the BAER teams using an immediate assessment of classified Landsat satellite imagery (Key and Benson 2006). Severity was then verified in the field using a modification of the Composite Burn Index (CBI) in which measurements for “intermediate trees” and “big trees” were excluded due to their absence from these piñon-juniper woodlands (Key and Benson 2006). The site is located on members of the Kayenta, Navajo and Mojave sandstone parent material, which are generally characterized by low salinity, neutral pH and sandy texture (Harper et al. 2003).

This study focused on plots that were already present in a previous study and consisted of a paired plot design with untreated control and herbicide treated plots. All plots were established prior to the aerial application of herbicide. The plots were randomly located within the study area and the treatment types were randomly assigned to plots (Fig. 2.1). The plot layout consisted of a five by 30 m plot nested within a 30 m CBI plot. To insure the integrity of the control plots, each plot was buffered by 15 m and the helicopter avoided spraying these buffered areas. Additional factors were taken into consideration when determining plot locations such as avoidance of large washes and slopes < 45%.

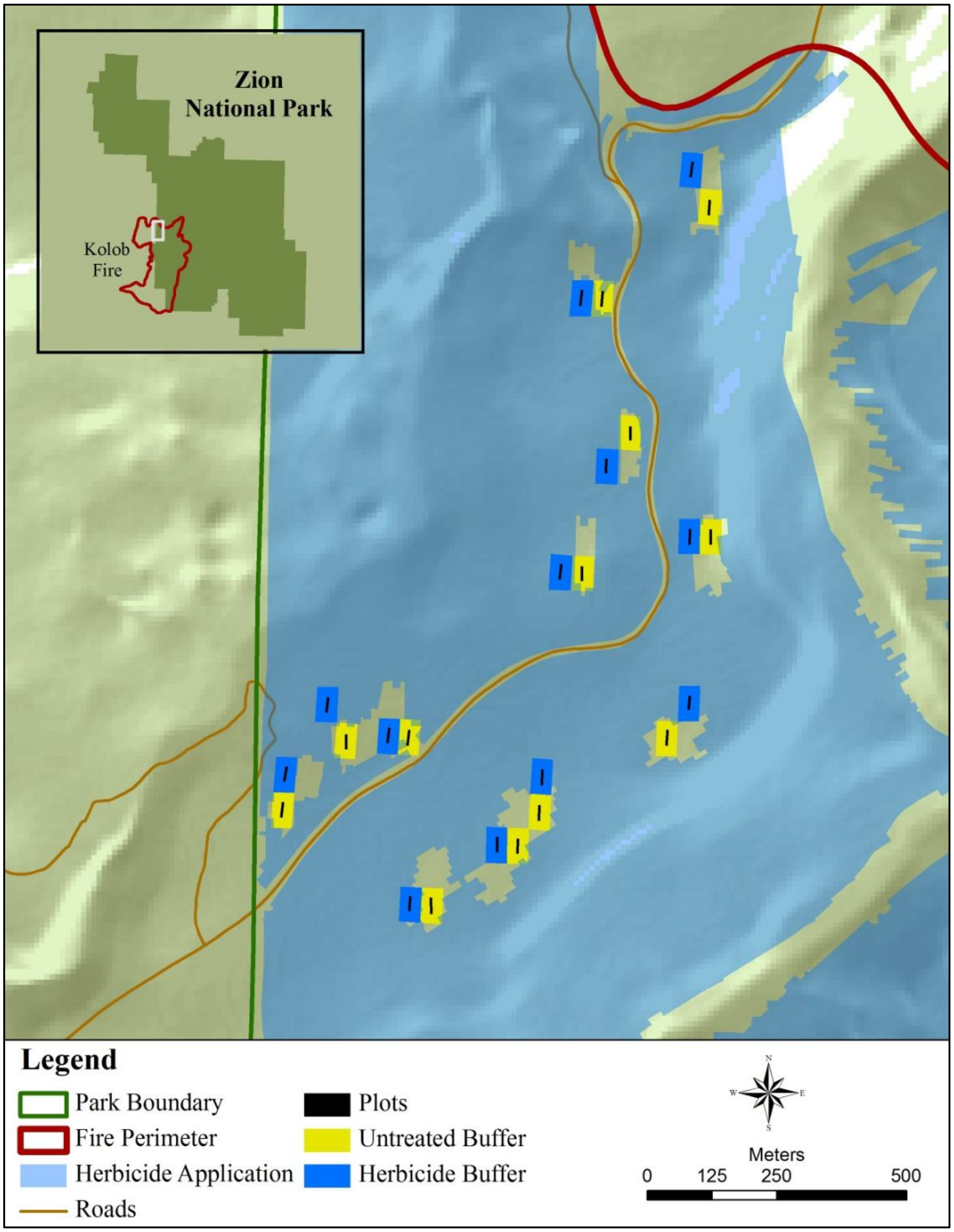


Figure 2. 3: Map of the location of plots in the study area. Blue and yellow polygons represent the buffers around the plots, which are represented by black polygons. The blue overlay represents the actual helicopter swaths of the herbicide application.

2.3 Seed Collection Methods

To capture the response of the cheatgrass in the first spring after the herbicide application (spring of 2007), cheatgrass seeds were obtained from biomass samples collected in the spring of 2007. On each plot between one and five subsamples of cheatgrass biomass were collected, and seeds for the germination study were obtained equally among the subsamples to capture any variation on the plot-scale. Since the cheatgrass plants in the biomass samples were not intended to be used to provide seed for a germination study, the plants were not all collected at full maturity and they were subjected to a heated drying process. The seeds obtained from the spring 2008 cheatgrass biomass samples were not developed due to early biomass collection and could not be tested. Due to the early biomass collection again during the spring of 2009, seeds for the germination study were randomly collected from cheatgrass plants in the field once they reached the point of senescence. Seeds were collected from the buffers around the herbicide treated and untreated control plots to assure this study would not affect future sampling, and collections resulted in a sample size of nine paired plots.

2.4 Laboratory Methods

The seeds from the spring of 2007, which were taken from biomass samples, were left in paper bags at room temperature (after the heated drying process) for approximately one year before starting the germination study. According to Allen et al. (1994), cheatgrass seed dormancy levels decrease as a function of storage time, therefore seeds that were collected in the field during the spring of 2009 were left in paper bags at room temperature (and not subjected to the heated drying process) for six months prior to the germination study to assist in breaking any dormancy. The seeds from each plot were randomly split between four petri dishes resulting in 25 seeds per petri dish. Each petri dish was lined with two pieces of filter paper to help retain moisture, and each dish was covered. The dishes were blocked by plot in the growth chamber to assure any microclimatic differences within the chamber would not affect the results. The growth chamber was set on the following settings: daytime temperatures of 30^{o}C, nighttime temperatures of 20^{o}C and relative humidity of 75% (Beckstead et al. 1996). Daytime and nighttime temperatures were each set for a duration of 10 hours with two hours of stepwise heating/cooling in the interim. Water was added to the filter paper until paper was fully moistened every other day to assure full germination was reached. We considered seeds germinated, and therefore viable, when the radicle reached two mm long (Beckstead et al. 1996; Meyer and Allen 1999). Germinated seeds were removed from the dishes as they were counted. The study ran until no seeds germinated for two weeks. The remaining seeds were assumed to be non-viable or dormant.

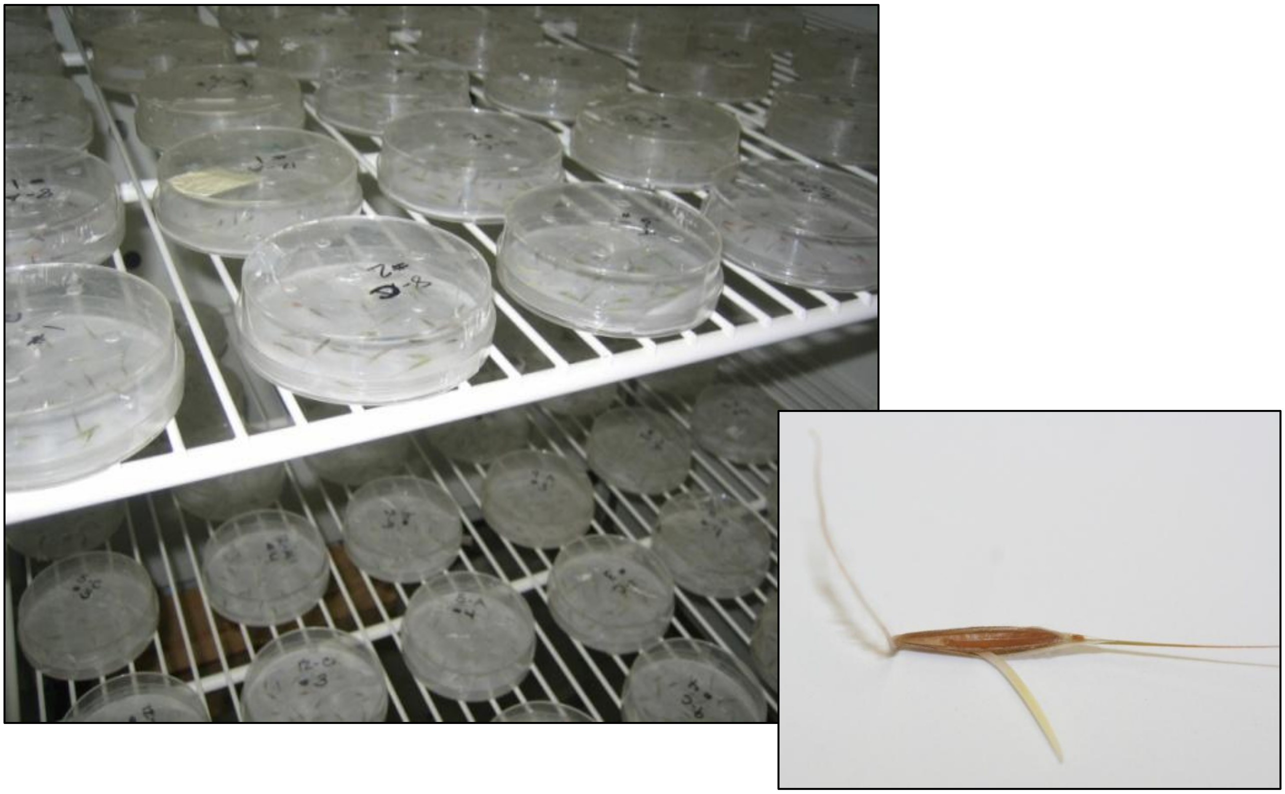


Figure 2. 4: Petri dishes in the germination chamber. Inset shows a germinated cheatgrass seed.

2.5 Statistical Methods

The response variable measured for this study was the number of seeds germinated. Normality of the residuals was evaluated using visual tests (i.e., Q-Q plots) and Shapiro-Wilk tests. The data were normal; therefore, paired t-tests were performed to test for differences between seeds collected from treated and untreated plots. Tests were performed on the number of seeds that had germinated as of each day of the study, and all tests for normality and paired t-tests were performed in R Statistical software base package (R Development Core Team 2009).

3 Results and Discussion

Cheatgrass is well known for having very high germination rates, as this is one of the attributes that makes it such a successful competitor (Young and Allen 1997). Therefore the use of imazapic herbicide would be considered even more efficacious if those plants treated with the herbicide demonstrated lower germination numbers. Unfortunately the seeds from the first year of the study were not collected at full maturity and were then subjected to high temperatures in a biomass drying process. The combination of these factors likely contributed to the overall low germination rates from this season. Seventy-five percent of 2007 seeds that germinated did so in the first week of the study; germination ceased after 15 days. All other seeds were considered non-viable or dormant. The seeds from untreated plots reached an average germination rate of 27%, while the seeds from treated plots reached an average germination rate of 43% (Fig. 3.2). Due to the high variability in germination, no differences between untreated and treated plots were statistically significant.

The seed collected during the spring of 2009, however, demonstrated germination numbers and trends that partially supported my hypothesis that the cheatgrass growing on imazapic treated plots would demonstrate lower germination rates. The seeds collected at full development in the spring of 2009 reached much higher germination rates (more than 90% within the first week) and demonstrated a different trend from that in 2007. The seeds collected in the spring of 2009 also reached full germination potential after 15 days in the germination chamber. The seeds from untreated plots reached an average germination rate of 99% while those collected from treated plots reached an average germination rate of 92%. The differences between germination rates on untreated and treated plots were significantly different only on day seven of the study, approximately the time that the rate of germination reached a plateau. Furthermore, by the spring of 2009, the density of cheatgrass plants on treated and untreated plots was not statistically different, however the size of individual cheatgrass plants on treated plots was significantly larger than that of cheatgrass on untreated plots (Thode, unpublished data). These larger cheatgrass plants in the imazapic treated areas may produce more seed and reach minimum fuel thresholds more quickly, which would result in the further perpetuation of fire and cheatgrass (Ziska et al. 2005). This phenomenon could be due to cheatgrass's ability to utilize excess nutrients as a result of the overall lower aboveground biomass on treated plots (Monaco et al. 2005), which in 2009 overall aboveground biomass on treated plots remained approximately half of that of untreated plots (Thode, unpublished data). Regardless, it is important to note that cheatgrass produces far more seeds than necessary to contribute to the following years population (Monsen 1992), and the fact that cheatgrass on treated plots is producing a seed crop that is 92% viable less than three years post-treatment is not encouraging.

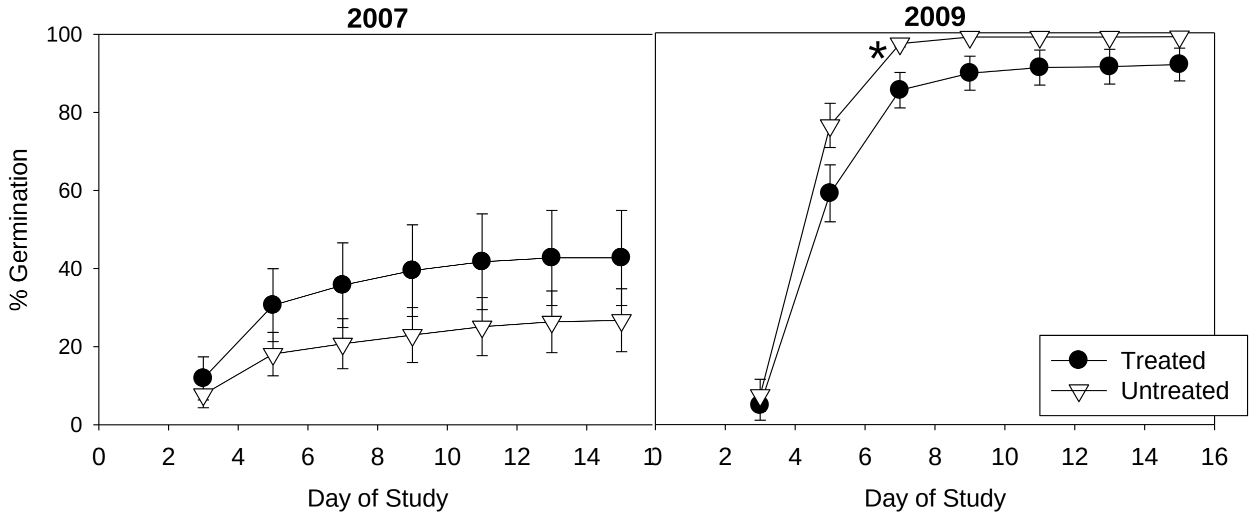


Figure 3. 1: Average (+ SE) germination percentage of cheatgrass from **A**, spring 2007 and **B**, spring 2009. Significantly different means ($p<0.05$, degrees of freedom=8) are indicated by an asterisk.

4 Management Implications

Although this study was imperfect in its first season, the results indicate that cheatgrass was able to establish in imazapic treated plots and produced viable seeds for the following year. Furthermore, by the third year post-treatment, cheatgrass plants growing in treated and untreated plots attained similar germination rates—amply sufficient to replace and expand the current populations. Additionally, by the third year post-treatment the cheatgrass plants growing in imazapic treated areas attained similar densities to untreated areas, but individual plant aboveground biomass in treated areas was twice that of untreated areas (Thode, unpublished data). Although imazapic may retard the germination and growth of cheatgrass in the first generation post-treatment, this study indicates that cheatgrass in these areas will reach reproduction rates sufficient to allow the areas to be reinvaded by this persistent annual grass. It is important to consider all potential side effects and disturbances associated with restoration projects, as it appears that the application of imazapic was not sufficient to retard cheatgrass germination and aid in the establishment of a native plant community capable of excluding cheatgrass.

Overall Management Implications

Cheatgrass (*Bromus tectorum* L.) is an invasive annual grass that was introduced to North America in the late 1800s and has since spread to occupy over 40 million ha across the West (Mack 1981). Once introduced, cheatgrass can dominate a disturbed area within only five years (Morrow and Stahlman 1984), and is responsible for reduced richness and diversity of native plants through the formation of monocultures (Monsen 1992). It contributes to a buildup of fine dry fuels which can change fire regimes by extending the fire season both earlier and later in the year and reduces the fire return interval in many ecosystems (Brooks et al. 2004; Klemmedson 1964; Knapp 1996; Ziska et al. 2005). In response to these concerns about cheatgrass, Zion National Park staff have adapted a proactive approach for dealing with this issue. After the Kolob and Dakota Hill Fires burned throughout the Park during the summers of 2006 and 2007, imazapic herbicide was applied by helicopter in attempt to retard cheatgrass invasions post-fire. However, the implications of herbicide applications at this scale to a post-fire environment are not fully understood, and Park employees had the foresight to implement monitoring projects on both fires to better understand the effects of imazapic herbicide on both cheatgrass invasions and the native understory plant communities. Thus, the findings of this research are imperative to future management decisions since imazapic herbicides have not been widely used at large scales post-fire.

It is important to note that the Dakota Hill site may not be exemplary of most due to the presumed limited pre-fire cheatgrass presence, and in this case the threat of cheatgrass invasion may have been smaller than the damage to the native species by the imazapic herbicide. Although there was too little cheatgrass colonizing both treated and untreated areas through the duration of this study to see any treatment effects, this research indicates that when applied post-fire as a pre-emergent herbicide, imazapic reduces the richness, aboveground biomass, density and aerial cover of many native species. This was demonstrated by the overall lower shrub densities and native species richness, aboveground biomass, density and aerial coveron treated plots in both the piñon-juniper dominated and Gambel oak dominated communities. Furthermore, this research indicates that regardless of whether the imazapic is still active in the soil two years post-application, there are still large deviations between the untreated and treated plots. The species that tend to be most affected encompass all life histories and life forms and range from annual forbs and grasses, to perennial forbs and shrubs. Additionally, some of the most common species were also the ones that were most affected by the herbicide, potentially resulting in greater impacts to the overall vegetation community on treated plots. The differences in community compositions further indicate that the application of imazapic may have set the communities on different successional trajectories which may never resemble those within their historical ranges of variability.

The reductions in overall vegetation create more open growing space for species to establish. Unfortunately, if cheatgrass is present, it is possible that the overall lack of complete control demonstrated by other studies (Baker et al. 2009; Matchett et al. 2009a; Thode et al. 2010) coupled with the delayed recovery of native species in treated areas could allow this quickly establishing invasive grass a further advantage over native species (Monaco et al. 2005). Although other studies have indicated that burning prior to the use of imazapic herbicides provides better control of cheatgrass (Matchett et al. 2009b), this study indicates that it also appears to reduce native species aboveground biomass, density and aerial cover. Establishment of these native species is essential to restore fire regimes to historical conditions and thereby achieve long term cheatgrass control; however, this imazapic treatment may make the successful establishment of native species very difficult.

In addition to studying the native plant community, it is important to understand more specifically how imazapic herbicide affects cheatgrass. Multiple studies have noted that although there are reductions in cheatgrass density post-application, some cheatgrass plants do establish in treated areas (Baker et al. 2009; Matchett et al. 2009b; Thode et al. 2010). If these plants are still capable of reproducing then although the post-application invasion of cheatgrass may be retarded, the characteristic prolific seed production of cheatgrass (Young and Allen 1997) will still allow this species to quickly establish and spread. The results of the germination trial in this study indicate that cheatgrass that was able to establish in imazapic treated plots produced viable seeds for the following year. Furthermore, by the third year post-treatment, cheatgrass plants growing in treated and untreated plots attained similar germination rates—amply sufficient to replace and expand the current populations. Although imazapic may retard the germination and growth of cheatgrass in the first generation post-treatment, this study indicates that by the third season cheatgrass in these areas will reach reproduction rates sufficient to allow the areas to be reinvaded by this persistent annual grass.

When coupled, the results of these two studies suggest that in some cases a post-fire broadcast application of imazapic herbicide may actually be detrimental to restoration goals. The imazapic herbicide application resulted in a native plant community with lower species richness and lower overall plot aboveground biomass, density and aerial cover, which allowed for continued open growing space and available nutrients for species such as cheatgrass, which is typically capable of prematurely utilizing available resources (Allen et al. 1994; Jessop and Anderson 2007). Furthermore, if cheatgrass plants do establish on the treated areas, the germination trials indicate that they will reach sufficient reproduction rates to expand the cheatgrass population. It is important to consider all potential side effects and disturbances associated with restoration projects (McGlone et al. 2009), as it appears that these broadcast applications of imazapic were not sufficient to retard cheatgrass germination and aid in the establishment of a native plant community capable of excluding cheatgrass. Although the application of imazapic herbicide proved detrimental to the landscape in this instance, there may be situations in which its use could be beneficial. If the area is highly degraded with few or no remaining native species, the application could be warranted. Furthermore, imazapic herbicide could be effective if used prior to revegetation projects or on isolated cheatgrass patches. When broadcast over large areas, however, a sequence of burning and imazapic herbicide is likely not enough to control cheatgrass and restore native habitats, and other methods must be considered, either alone or in conjunction with burning and imazapic herbicide applications.

Literature Cited

Abella, S. R., and P. Z. Fulé. 2008. Fire effects on Gambel oak in southwestern ponderosa pine-oak forests. Fort Collins, CO, USA: US Department of Agriculture, Forest Service, RMRS-RN-34. 6 p.

Allen, P. S., S. B. Debaene-Gill, and S. E. Meyer. 1994. Regulation of germination timing in facultatively fall-emerging grasses. *In*: S. B. Monson and S. G. Kitchen [ED.] Proceedings--Ecology and Management of Annual Rangelands. Ogden, UT, USA: US Department of Agriculture, Forest Service, INT-GTR-313. p. 215-219.

Baker, W. L., J. Garner, and P. Lyon. 2009. Effect of imazapic on cheatgrass and native plants in Wyoming big sagebrush restoration for Gunnison Sage-grouse. *Natural Areas Journal* 29:204-209.

Baker, W. L., and D. J. Shinneman. 2004. Fire and restoration of piñon–juniper woodlands in the western United States: a review. *Forest Ecology and Management* 189:1-21.

Balda, R. P., and N. Masters. 1980. Avian communities in the pinyon-juniper woodland: a descriptive analysis. *In* R. M. DeGraaf [TECH. COORD.], Workshop proceedings: Mangement of Western Forests and Grasslands for Nongame Birds. Salt Lake City, UT, USA: US Department of Agriculture, Forest Service, INT-86. p. 146-169.

Barger, R. L., and P. F. Ffolliott. 1972. Physical characteristics and utilization of major woodland tree species in Arizona. Fort Collins, CO, USA: US Department of Agriculture, Forest Service, Research Paper RM-83. 80 p.

Barnes, T. G. 2007. Using herbicides to rehabilitate native grasslands. *Natural Areas Journal* 27:56-65.

Beckstead, J., S. E. Meyer, and P. S. Allen. 1996. *Bromus tectorum* seed germination: Between-population and between-year variation. *Canadian Journal of Botany-Revue Canadienne De Botanique* 74:875-882.

Beran, D. D., R. E. Gaussoin, and R. A. Masters. 1999a. Native wildflower establishment with imidazolinone herbicides. *Horticultural Science* 34:283-286.

Beran, D. D., R. A. Masters, and R. E. Gaussoin. 1999b. Grassland legume establishment with imazethapyr and imazapic. *Agronomy Journal* 91:592.

Beyer, H. L. 2004. Hawth's Analysis Tools for ArcGIS, version 3.27.

Brooks, M. L., C. M. D'Antonio, D. M. Richardson, J. B. Grace, J. E. Keeley, J. M. DiTomaso, R. J. Hobbs, M. Pellant, and D. Pyke. 2004. Effects of invasive alien plants on fire regimes. *Bioscience* 54:677-688.

Bruner, A. D., and D. A. Klebenow. 1979. Predicting success of prescribed fires in pinyon-juniper woodlands in Nevada. Ogden, UT, USA: US Department of Agriculture, Forest Service, Research Paper INT-219. 11 p.

Clarke, K. R., P. J. Somerfield, and M. G. Chapman. 2006. On resemblance measures for ecological studies, including taxonomic dissimilarities and a zero-adjusted Bray–Curtis coefficient for denuded assemblages. *Journal of Experimental Marine Biology and Ecology* 330:55-80.

Clary, W. P., and A. R. Tiedemann. 1986. Distribution of biomass within small tree and shrub form *Quercus gambelii* stands. *Forest Science* 32:234-242.

Crane, M. F. 1982. Fire ecology of Rocky Mountain Region forest habitat types. Missoula, MT, USA: US Department of Agriculture, Forest Service, Unpublished Final Report.

Davison, J. C., and E. G. Smith. 2007. Imazapic provides 2-year control of weedy annuals in a seeded Great Basin fuelbreak. *Native Plants Journal* 8:91-96.

Doelling, H. H., G. C. Willis, B. J. Solomon, E. G. Sable, W. L. Hamilton, and L. P. N. II. 2002. Interim geologic map of the Springdale East quadrangle [Zion National Park], Washington County, Utah.

Eddington, D. B. 2006. Effects of cheatgrass control on Wyoming big sagebrush in southeastern Utah [thesis]. Provo, UT, USA: Brigham Young University. 39 p.

Erdman, J. A. 1970. Pinyon-juniper succession after natural fires on residual soils of Mesa Verde, Colorado. *Brigham Young University Science Bulletin-Biological Series* 11:1.

Floyd, M. L., W. H. Romme, and D. D. Hanna. 2000. Fire history and vegetation pattern in Mesa Verde National Park, Colorado, USA. *Ecological Applications* 10:1666-1680.

Frasier, G. W. 1992. Establishment Characteristics of Cheatgrass Under Various Wet-Dry Watering Sequences. *In*: S. B. Monson and S. G. Kitchen [ED.] Proceedings--Ecology and Management of Annual Rangelands. Ogden, UT, USA: US Department of Agriculture, Forest Service, INT-GTR-313. p. 225-228.

Fulé, P. Z., D. C. Laughlin, and W. W. Covington. 2005. Pine-oak forest dynamics five years after ecological restoration treatments, Arizona, USA. *Forest Ecology and Management* 218:129-145.

Gatewood, R. 2007. Dakota Hill Complex Burned Area Emergency Response Plan. National Park Service, U.S. Department of the Interior.

Gennari, M., M. Negre, and D. Vindrola. 1998. Adsorption of the herbicides imazapyr, imazethapyr and imazaquin on soils and humic acids. *Journal of environmental science and health. Part B. Pesticides, food contaminants, and agricultural wastes* 33:547-567.

Harper, K. T., S. C. Sanderson, and E. D. McArthur. 2003. Pinyon-juniper woodlands in Zion National Park, Utah. *Western North American Naturalist* 63:189-202.

Harper, K. T., F. J. Wagstaff, and L. M. Kunzler. 1985. Biology and management of the Gambel oak vegetative type: a literature review. Ogden, UT, USA: US Department of Agriculture, Forest Service, INT-179. 31 p.

Hulbert, L. C. 1955. Ecological studies of *Bromus tectorum* and other annual bromegrasses. *Ecological Monographs* 25:181-213.

Hull, A. C., and W. T. Hansen. 1974. Delayed Germination of Cheatgrass Seed. *Journal of Range Management* 27:366-368.

Jessop, B. D., and V. J. Anderson. 2007. Cheatgrass invasion in salt desert shrublands: Benefits of postfire reclamation. *Rangeland Ecology & Management* 60:235-243.

Key, C. H., and N. C. Benson. 2006. Landscape assessment (LA): sampling and analysis methods. Ogden, UT, USA: US Department of Agriculture, Forest Service, RMRS-GTR-164-CD.

Klemmedson, J. O. 1964. Cheatgrass (*Bromus Tectorum* L). *Botanical Review* 30:226-262.

Knapp, P. A. 1996. Cheatgrass (*Bromus tectorum* L.) dominance in the Great Basin Desert - History, persistence, and influences to human activities. *Global Environmental Change-Human and Policy Dimensions* 6:37-52.

Kottek, M., J. Grieser, C. Beck, B. Rudolf, and F. Rubel. 2006. World map of the Koppen-Geiger climate classification updated. *Meteorologische Zeitschrift* 15:259-264.

Kyser, G. B., J. M. DiTomaso, M. P. Doran, S. B. Orloff, R. G. Wilson, D. L. Lancaster, D. F. Lile, and M. L. Porath. 2007. Control of medusahead (*Taeniatherum caput-medusae*) and other annual arasses with imazapic. *Weed Technology* 21:66-75.

Laughlin, D. C., J. D. Bakker, and P. Z. Fulé. 2005. Understorey plant community structure in lower montane and subalpine forests, Grand Canyon National Park, USA. *Journal of Biogeography* 32:2083-2102.

Mack, R. N. 1981. Invasion of *Bromus tectorum* L. into western North America: an ecological chronicle. *Agro-Ecosystems (Netherlands)* 7:145-165.

Mack, R. N., and D. A. Pyke. 1983. The demography of *Bromus tectorum*: variation in time and space. *The Journal of Ecology* 71:69-93.

Masters, R. A., S. J. Nissen, R. E. Gaussoin, D. D. Beran, and R. N. Stougaard. 1996. Imidazolinone herbicides improve restoration of Great Plains grasslands. *Weed Technology* 10:392-403.

Matchett, J. R., A. O'Neill, M. Brooks, C. Decker, J. Vollmer, and C. Deuser. 2009. Reducing fine fuel loads, controlling invasive annual grasses, and manipulating vegetation composition in Zion Canyon, Utah. El Portal, CA, USA: US Department of the Interior, US Geological Survey, Final Report for Joint Fire Science Program Project 05-2-1-13. 30 p.

McCune, B., J. B. Grace, and D. L. Urban. 2002a. Analysis of ecological communities. MjM Software Design Gleneden Beach, Oregon, USA.

McCune, B., D. Keon, and R. H. Marrs. 2002b. Equations for potential annual direct incident radiation and heat load. *Journal of Vegetation Science* 13:603-606.

McCune, B., and M. J. Mefford. 2006. PC-ORD 5.0 multivariate analysis of ecological data. MjM Software, Gleneden Beach, OR.

McGlone, C. M., J. D. Springer, and D. C. Laughlin. 2009. Can pine forest restoration promote a diverse and abundant understory and simultaneously resist nonnative invasion? *Forest Ecology and Management* 258:2638-2646.

Melgoza, G., and R. S. Nowak. 1991. Competition between cheatgrass and two native species after fire - implications from observations and measurements of root distribution. *Journal of Range Management* 44:27-33.

Meyer, S. E., and P. S. Allen. 1999. Ecological Genetics of Seed Germination Regulation in *Bromus tectorum* L. I. Phenotypic Variance among and within Populations. *Oecologia* 120:27-34.

Monaco, T., D. Johnson, J. U. Norton, and E. U. Leonard. 2005. Altering Plant-Successional Trajectories Following Wildfire in Sagebrush-Steppe Communities. *In*: ASA-CSSA-SSSA Annual Meeting Abstracts; 6-10 November 2005; Salt Lake City, UT, USA.

Monsen, S. B. 1992. The competitive influences of cheatgrass (*Bromus tectorum*) on site restoration. *In*: Symposium on Ecology, Management, and Restoration of Intermountian Annual Rangelands; 18-21 May 1992; Boise, ID, USA. p. 43-50.

Mooney, H. A., and E. E. Cleland. 2001. The evolutionary impact of invasive species. *Proceedings of the National Academy of Sciences* 98:5446.

Morrow, L. A., and P. W. Stahlman. 1984. The history and distribution of downy brome (*Bromus tectorum*) in North America. *Weed Science* 32:2-6.

Mueller-Dombois, D., and H. Ellenberg. 1974. Aims and methods of vegetation ecology. New York, NY, USA: John Wiley. 574 p.

Pimentel, D., R. Zuniga, and D. Morrison. 2005. Update on the environmental and economic costs associated with alien-invasive species in the United States. *Ecological Economics* 52:273-288.

R Development Core Team. 2010. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

Romme, W. H., C. D. Allen, J. D. Bailey, W. L. Baker, B. T. Bestelmeyer, P. M. Brown, K. S. Eisenhart, L. Floyd-Hanna, D. W. Huffman, and B. F. Jacobs. 2008. Historical and Modern Disturbance Regimes, Stand Structures, and Landscape Dynamics in Piñon Juniper Vegetation of the Western US. Colorado Forest Restoration Institute, Fort Collins, CO, USA.

Simonin, K. 2000. *Quercus gambelii*. Fire Effects Information System [Online]. URL: http://www.fs.fed.us/database/feis/. Accessed 17 January 2010.

Stewart, G., and A. C. Hull. 1949. Cheatgrass (*Bromus Tectorum* L.) - an Ecologic Intruder in Southern Idaho. *Ecology* 30:58-74.

USDI National Park Service. 2003. Fire Monitoring Handbook. Boise (ID): Fire Management Program Center, National Interagency Fire Center. 274p.

Thode, A. E., K. Weber, K. Haubensak, H. Brisbin, and M. Brooks. 2010. Treatment effectiveness monitoring for the Kolob Fire burned area rehabilitation treatments. Final Report to Zion National Park.

Tiedemann, A. R., W. P. Clary, and R. J. Barbour. 1987. Underground systems of Gambel oak (*Quercus gambelii*) in central Utah. *American Journal of Botany* 74:1065-1071.

Tu, M., C. Hurd, and J. M. Randall. 2004. Imazapic. Weed control methods handbook. London: Academic. p. 1-7.

USDA-NRCS. 2009. The PLANTS database. Available at: http://plants.usda.gov. Accessed 1 April 2010.

Vitousek, P. M. 1990. Biological invasions and ecosystem processes: towards an integration of population biology and ecosystem studies. *Oikos* 57:7-13.

Vollmer, J. L., and J. G. Vollmer. 2008. Controlling cheatgrass in winter range to restore habitat and endemic fire. *In* S. G. Kitchen, R. L. Pendleton, T. A. Monaco, J. Vernon [COMPS.]. Proceedings--Shrublands under fire: disturbance and recovery in a changing world; 6-8 June 2006; Cedar City, UT, US. Fort Collins, CO: US Department of Agriculture, Forest Service RMRS-P-52.

West, N. E. 1999. Distribution, composition, and classification of current juniper-pinyon woodlands and savannas across western North America. *In*: S. B. Monsen, R. Stevens [COMPS.] Proceedings: ecology and management of pinyon-juniper communities within the Interior West; 15-18 September 1997; Provo, UT, USA. Ogden, UT, USA: US Department of Agriculture, Forest Service, RMRS-P-9. p. 20-23.

Young, J. A., and F. L. Allen. 1997. Cheatgrass and range science: 1930-1950. *Journal of Range Management* 50:530-535.

Young, J. A., and C. D. Clements. 2000. Cheatgrass control and seeding. *Rangelands* 22:3-7.

Young, J. A., and R. A. Evans. 1978. Population dynamics after wildfires in sagebrush grasslands. *Journal of Range Management* 31:283-289.

Ziska, L. H., J. B. Reeves III, and B. Blank. 2005. The impact of recent increases in atmospheric CO2 on biomass production and vegetative retention of cheatgrass (*Bromus tectorum*): implications for fire disturbance. *Global Change Biology*: 11: 1325-1332.

Appendix A. Study 1 Field Protocols

Overview:

- The plot design is based on the NPS Fire Monitoring Handbook and was modified by the USGS and previous NAU graduate students.
- The plot is a 5x30 m brushbelt oriented North-South and has a Composite Burn Index (CBI) laid over it
- All plant measurements will be taken inside the brushbelt
- Soil sampling for nutrient analysis will occur just outside of the brushbelt
- Each brushbelt is set up with 2 rebar per plot, each with a tag. The orange rebar marks the SW corner and the pink rebar marks the NW corner. The east side of the plot is marked by large nails spray painted orange and pink to correspond with the rebar.
- The tags contain important information and are set up as follows:

  The first letter corresponds to the vegetation type: P = Pinon-Juniper
  G = Gamble Oak
  The number that follows is the plot number (1-18 for each vegetation type)
  The last letter corresponds to the treatment: T = treated with herbicide
  U = untreated control
  The number at the bottom of the tag corresponds to the meter mark where the rebar is located:
  0 = the SW corner of the plot—start running the tape from here
  30 = the NW corner of the plot—run the tape to this rebar

  Example of a tag: P – 12 – U
  0

  This plot is number 12 in the Pinon-Juniper vegetation type, was not treated with herbicide and is on the rebar located at the SW corner of the plot.

- **IT IS VERY IMPORTANT TO NOT WALK IN THE PLOT**—these plots will be sampled for 6 seasons and need to remain as undisturbed as possible!

How to set up the Brushbelt:

- Run the 30 m tape from the orange rebar due north to the pink rebar (the pink rebar should be located at 30.3 m)
- Most brushbelts contain nails along the ground that were placed along this tape to mark the locations of five density frames, use these to ensure you are running the tape the same way as previous years.

- When walking along the brushbelt with the tape, walk a few feet outside the brushbelt holding your arm out towards the brushbelt in order to reduce brushbelt destruction.
- Try not to throw the tape. When it is unavoidable, throw it to a location a few feet off the edge of the plot but around the object that is in your way.
- DO NOT wrap the tapes around the rebar or nails as this puts a lot of pressure on the end of the tape and could cause it to break
- Run the east tape from the SE orange nail due north to the NE pink nail (the pink nail should be located at exactly 30 m)
- Finish by running the 5 m tapes from the rebars to the corresponding nails

MEASUREMENTS TAKEN AT EACH BRUSHBELT:

Pinon-Juniper:

Appendix B. Pictures
2. Point Transect (west 30 meters)
3. Density/Cover frames (west 5 1x1 m subplots)
4. Richness
5. Shrub Density
6. Biomass (east 5 0.5x1 m subplots)

Gambel Oak:

Appendix B. Pictures
2. Shrub/Line Transect (west transect (0 m) & middle of plot (3 m))
3. Density/Cover frames (west 5 1x1 m subplots)
4. Richness
5. Shrub Density
6. Biomass (east 5 1x0.5 m subplots)

Measurement How To:

1. **Pictures—**A minimum of 4 pictures will be taken at each brushbelt in order to document the overall changes in the brushbelt from year to year. It may take more pictures to characterize the brushbelt…do not hesitate to take more or ask if more are necessary.

Always be sure to keep the camera in the pelican case when not in use. Do not set the camera on the ground as dirt can easily damage it. Also, be sure to only turn the camera on when it will be in immediate use—batteries are a precious commodity in the backcountry.

All brushbelt pictures are to be taken with the camera held for a landscape view (as opposed to portrait). The camera should always be held at eye level in order to obtain standardized photos.

Each picture should have the wipe board in it showing the brushbelt ID, the date, the photographer's initials, and what view of the brushbelt is being taken. The wipe board can be placed outside the brushbelt leaning against something (the rebar, a backpack, etc.), or another crew member may hold the wipe board so it is legible in the photo, but not blocking the view of the brushbelt.

The following are the wipe board labels for each view of the brushbelt:

> **0-30 m**: This picture is taken from the orange rebar towards the pink rebar. Stand a few feet back from the orange rebar in order to get the top of the rebar in the field of view and take it STRAIGHT down the line. If possible, capture the pink rebar at the other end of the brushbelt in line with the orange rebar.
>
> **30-0 m**: This picture is the opposite of the 0-30 m picture and is taken from the pink rebar straight towards the orange rebar
>
> **S-N**: This picture is taken from the south end of the brushbelt towards the north end of the brushbelt. To take this picture stand in the middle of the South end of the brushbelt and back up until the south rebar and large spray painted nail are in the field of view. Take this picture straight down the center of the plot, capturing the south, east, and west tapes delineating the plot.
>
> **N-S**: This picture is the opposite of the S-N picture and is taken from the north end of the brushbelt towards the south end of the brushbelt.

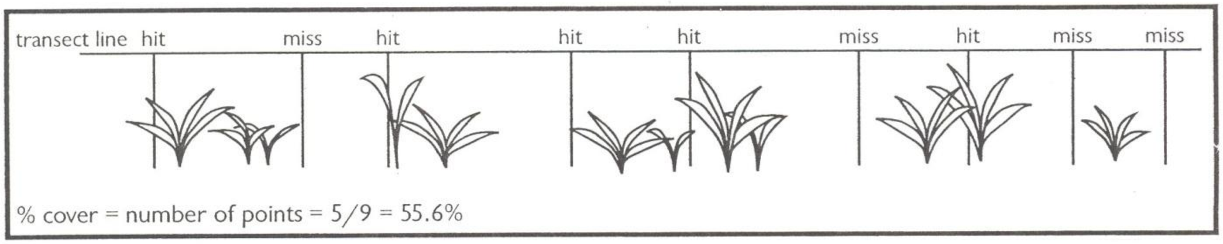
2. **Point Transect (PJ PLOTS ONLY)**—Along the west 30.3 m tape

Fill out all plot, date, and collector information on the Point Transect Datasheet.

All points at which measurements will be taken are recorded in the first column of the datasheet. The next 4 columns are for recording the vegetation. If the pole comes in contact with more than 4 different plants before hitting the substrate, mark the additional species in the notes column. Finally, record the type of substrate the pole hits in the "Substrate" column.

Starting at the 30 cm mark on the west 30.3 m tape, starting at a height of 2 m drop the pole straight down. Hold the pole as vertical as possible and only count the vegetation that touches the pointed tip of the pole.

Record each species that touches the tip of the pole. Count each individual only once at each point, even if it touches the pole multiple times.



Record species from tallest to shortest, down to the substrate (rock, litter, coarse woody debris (CWD), bare soil, scorched earth, etc.)

If the pole intersects the bole of a tree that is over 2 meter tall, record Bole

If the pole intersects a dead tree branch above the ground, record the species with a "D" next to it

If the pole intersects a dead tree branch that is on the ground but still attached to the tree, record "CWD" in the substrate column followed by the species.

Continue every 30 cm along the west side of the plot to 30 m, resulting in 100 points

3. **Shrub Transect (OAK PLOTS ONLY)—**At 0 m and 3 m running 30 meters south to north along (and down the center of) the plot

Fill out all plot, date, and collector information on the Shrub Transect Datasheet.

In the first column record the transect number for which you are currently collecting the data. When you encounter a shrub along the transect, record its 6 letter species code in the second column of the datasheet, then the start and stop point along the transect to the nearest centimeter.

Treat the transect of the tape like a plane. Walk along the tape. It may help to hold a pole vertical above the tape in order to more easily deduce where the shrubs intersect the plane of the tape. When the plane of the tape encounters a shrub species, record the species and cm mark where the cover of the species begins. Continue walking along the transect until you reach the point where the cover for the species ends. Record this end point.

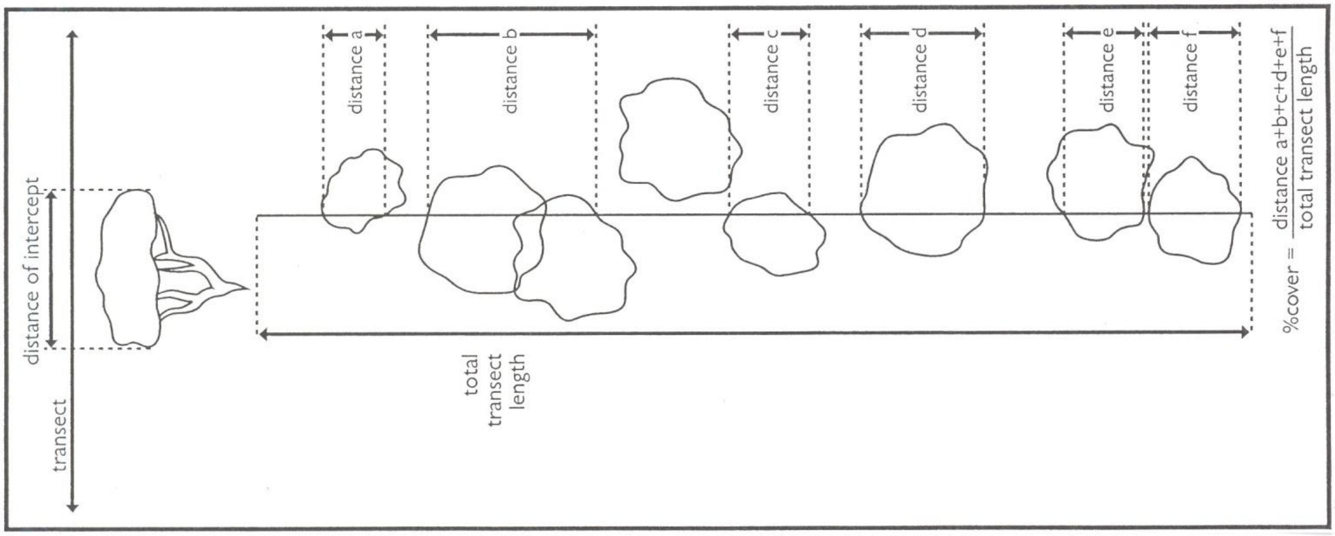
If you encounter a canopy gap that is larger than 5 cm, count this as the endpoint of the shrub and start a new entry for the next continuous shrub cover.

There is no minimum for recording the cover of a shrub. If it only intersects the tape for 1 cm, you do have to record it.

One start and end point may include many individuals **of the same species** being recorded as long as there is continuous cover along the plane of the transect tape.

If a second shrub species is encountered during the measurement of the first species, record this cover by species under a different entry.

For each shrub encountered, record an approximate average height of the **entire** shrub (not just the part of the shrub that intersects the plane of the tape). If there are multiple overlapping individuals of the same species recorded under one measurement, average all of the heights of the individuals into one measurement.



4. **Density & Cover Frames—**Along the west 30.3 m tape

Fill out all plot, date, and collector information on the Density/Cover Datasheet.

For each density/cover subplot be sure to mark the subplot number in the first column on the datasheet. Each species encountered in the subplot is to be recorded on the datasheet, along with the density and percent cover. Each subplot will also need records for any substrates in the subplot (rock, litter, coarse woody debris (CWD), bare ground, scorched earth, scat). After all measurements are taken, add the percentages together and write this number in the “total cover for subplot” column in the datasheet.

Starting at 5m, place a 1x1m frame every 5m for a total of 5 frames (at 5-6 m, 10-11 m, 15-16 m, 20-21 m and 25-26 m)

Within the frame, every plant species encountered will be counted and given a cover estimate. Any plant with more than 50% root mass in the frame will be counted as in.

Cover estimates will be done by species and will be estimated to the nearest percentage (NOT cover classes). Cover estimates will also be made for rock, litter, coarse woody debris, bare ground, scat and scorched earth (as well as any other cover classes that may be encountered). The total cover may exceed 100% due to overlapping species, however, each frame must have a cover estimate of at least 94%.

If a species takes up less than 1% of the frame, simply record <1%. Do not attempt to estimate to decimal places of each percentage.

If there is a shrub species that is covering any of the subplot, record this as a cover estimate on the data sheet. If it is not rooted within the subplot, be sure to record this information in the notes column of the datasheet.

5. **Richness—**The entire 5x30m brushbelt will be used as a measure of species richness. All species found within the brushbelt will be recorded (individuals do not need to be counted).

   Fill out all plot, date, and collector information on the Richness Datasheet.

   Carefully walk throughout the plot (stepping on rocks if possible in order to have the smallest possible impact on the plot), and record the species code for all living species found in the plot.

   Even if a species is recorded on another datasheet (thereby giving us a record of its presence in the plot), record it on the richness datasheet. It is logistically easier to have a comprehensive list all in one place and not have to put it together later.

6. **Shrub Density—**Each shrub with over 50% of its base rooted within the brushbelt will be counted.

   Fill out all plot, date, and collector information on the Shrub Density Datasheet.

   Included in the shrub category are all tree species (pinon and juniper) and shrub species (not including Gambel oak in the oak plots).

Record all shrubs present in the plot by species, age class (immature, mature, dead), and the number of individuals within each category.

Any changes in age, species, or livingness will result in a new entry (i.e. tally for dead *Amelanchier utahensis* is different from tally for mature *Amelanchier utahensis*)

It is often difficult to tell what species a dead and defoliated shrub was. If a dead shrub is unidentifiable, mark “UDShrub” on the datasheet and fill in the density count.

OAK SITES: Do not record numbers for any oak species. Only record shrub density measurements for those species that are not oak.

7. **Biomass**—The biomass clip subplots are along the east 30m tape. Five subplots (measuring 1x0.5m) will be clipped each year with the location changing each year due to the destructive nature of biomass clipping. The clip subplots for the current season are listed at the top of the Biomass Datasheet. Each biomass subplot is designed with a 0.5m buffer around it in which you can carefully stand, lean, or sit without destroying future biomass clip subplots.

Fill out all plot, date, and collector information on the Biomass Datasheet.

Plants will be separated **by species** into paper bags (there are 2 sizes—use the one appropriate for the amount of plant clipped)

There are mailing labels printed out with spaces to write in all necessary information on the bag. Stick one label on each paper bag where it will be easily seen when the bag is folded and stapled. Fill out the label completely and accurately. The labels are slightly too large for the small biomass bags—DO NOT RIP OFF PART OF THE LABELS TO MAKE THEM FIT! These bags will be weighed and therefore all need to have the same base weight with the full label attached to correctly measure the plant mass. Instead, fold the label around the side of the bag.

Try to clip the plant at ground level. If you pull up the entire plant, clip off the rootmass at ground level before placing it in the bag (please try to leave the rootmass in the ground if it is a native perennial species)

All previous year’s growth will be sorted out and not placed in the bag. If there are dead parts on the plant that are obviously part of the present year’s growth, place it in the bag along with the rest of the plant.

Staple bags shut *compactly* with the written collection information visible and place in a laundry bag for easy transport.

8. **Soil Sampling—**We will be taking soil samples using a small soil corer to gather a representative sample of the top 10 cm of soil.

Walk around the plot and take approximately 4-6 samples evenly spaced around the plot (i.e. 2 on each side and 1 on each end) and approximately 1-5 meters outside of the plot.

Depress the core to approximately 10 cm deep and place all soil collected by the corer into a paper bag labeled with the complete plot ID, date, and collectors initials.

If the corer comes in contact with a large rock or root, that does not allow it to be depressed to 10 cm, empty the corer and move a meter to either side and try again.

This season we will only need about 100 grams of soil. Once all soil is placed in the bag, shake it up and dump out the majority of the soil. The bag should have about an inch of soil at the bottom.

Double bag the soil, fold the bags twice and staple once. Be sure the plot information is written clearly on the bag.

Once back at camp, place the soil in a laundry bag. It will need to be air dried, so if it is sunny, leave the laundry bag in the sun. Be sure not to get the soil wet in the paper bags, it will deplete the nutrients causing incorrect analyses and the paper bags rip very easily when wet.

Leaving The Plot:

- When reeling in a tape, do not stand in one place and pull it along the line—this will destroy the line for future sampling seasons.
- Walk a few feet away from the edge of the plot while reeling in the tape.
- Double check to be sure all equipment is packed up and we are not leaving anything behind.

Appendix B. Study 1 Sampling Specifications and Definitions

COVER

- When estimating cover, it is important to be "Brome-centric". In other words, it is necessary to analyze cover from the stand point of whether or not it could support the growth of a Bromus species. For example, if you encountered a bare rock it would be simply be classified as rock. However, if the rock had a soil-filled depression on top that was capable of supporting a Brome seedling, then that portion would be classified as soil and only the remainder of the rock would actually be included in the rock estimate. The following is a description of the cover classifications and instances where these classifications can be somewhat tricky:

    - Vegetation – Each living plant rooted within the frame is identified by species. Cover estimates are based upon a collective of all individuals within a species. Trees and shrubs are included in this category but estimates will only consider the portions 4.5 feet (Diameter at Breast Height) and lower. Branches and foliage that overhang the frame from outside of the subplot are also to be factored into cover estimates.
    - Rock - Rocks are defined as being 2.5cm (about the size of your thumb) or larger. All stones failing to meet this criterion will be classified as litter. Occasionally, large rocks or outcrops will have a ledge that protrudes above a different substrate. In these cases, the lower substrate will be accounted for as well as the entire rock. This is one example of where cover estimates may exceed 100%.
    - Litter – Litter consists of rocks smaller than 2.5cm, standing-dead herbaceous material, fallen needles and leaves, etc. Dead cactus species, especially Opuntia, must be analyzed on an individual basis. These species are often times highly desiccated. At first glance, it may appear that an individual takes up 10 percent of the frame, but on closer inspection, it may be that only 5-6 percent of plant would actually block the emergence of a Brome seedling.
    - Coarse Woody Debris (CWD) – CWD consists of any downed woody material that exceeds more than 1 percent of the entire frame. Include in this category is stumps (occupying more than 1 percent of the plot) that do not exceed a height of 30 cm. This measure will especially come into play at the Gamble oak sites which will contain many small stumps.
    - Bare ground (BG) – This category is reserved for exposed, unburned soil with no visible crust. When estimating the amount of bare ground, keep in mind that scorched earth will be tallied separately.
    - Scorched Earth (SE) - This can be identified as blackened soil and/or the presence of powdery gray/white residues.

- Bole – This classification is reserved for standing-dead trees and shrubs as well as solid stumps exceeding a height of 30 cm. Any individual matching the above criteria but occupying less than 1 percent of the plot, will be considered litter.
- Scat—There are a lot of mule deer in this area, so we will be counting scat as a separate cover measurement (be sure to look closely as deer scat and burned juniper berries can often have similar appearances at a glance).
- Moss – The presence of moss is to be recorded, even if it is less than 1 percent. *Lichens are not distinguished from their host substrate.
- Cryptogamic Crust (CRYPTO) – This classification is somewhat subjective. The fire likely killed any of the cryptogams that may be present out there, so they would be classified as litter. In some instances though, they may still be very compact and their living status will be hard to determine. On the occasions where they appear to still be functioning in their normal capacity and would actively prevent seedling emergence, they should be placed in this category.
- Other—If you come across anything that does not fit into one of the above categories place it here (i.e. bones, trash, antlers). Enter "Other" under the species category on the datasheet and write what it is in the notes section.

DENSITY

- Only living species, rooted at least 50 percent within the frame, will be considered for density counts. Distinguishing individuals can sometimes be problematic. The following is guide for dealing with specific plants and growth forms

  - Rhizomatous Plants **-** If two specimens are within 30 cm of each other (approximately from your wrist to your elbow), they will be considered the same individual. Since they are rhizomatous, the 30 cm measure is from any bunch within one individual to any other. Therefore, what at first glance may look like 5 individuals interspersed throughout the subplot, if each is within 30 cm of any other, will be counted as 1 individual. If there is what looks like one individual at each end of the subplot and they are more than 30 cm apart in the subplot, but have other "individuals" that are within 30 cm of both plants outside the subplot, they are still to be counted as one individual.
  - Bunchgrasses - If a distinct clump can be discerned then each clump will be counted as a single individual.
  - Bromes - In SPRING seasons, bromes are NOT to be counted with single stem counts. Feel the root collar and count as clumps. In the FALL, each individual stem is counted as an individual.

- Opuntia species - Counts will be based upon clumping and the number of root collars seen (i.e. if you do not see a root growing out of the ground and they are not distinctly two separate individuals, then count as one). In situations where you cannot be sure as to whether they are individuals, if 2 plants are within 30 cm of each other, they are to be considered the same individual.
- Yuccas - Distinguish individuals through a clumping technique similar to bunchgrasses.
- Mat-forming species - Remember that often individual shoots can form stolons and appear as new roots when it is actually the same individual. A continuous mat of such mat-forming species will be counted as the same individual.

BIOMASS

- Biomass samples will not be taken from Opuntia and yucca species, but density counts for any living seedlings encountered will be written on the datasheet for that frame.

UNKNOWN SPECIES

- Take a picture of the whiteboard with the plant number and date on it. Then take a picture of the unknown plant with an item in it for scale. (Chapstick, pencil, lines of a field notebook...)
- All unknowns will be given a code as follows:
    - Forbs: UDForb #___
    - Grasses: UDGrass#___
    - Shrubs: UDShrub#___
    - This season we will start numbering from 50 and continue in numeric order. The first UDForb will be numbered 50, the next 31 and so on. The first UDGrass will also have the number 50.
- Look OUTSIDE the plot for other specimens to gather for pressing and identification purposes. If possible, gather multiple specimens. Record in your field notebook the unique code for the plant, the plot in which it was found, date it was collected, name of the collector, the picture number, how many specimens were collected, and a detailed description of the plant including any diagnostic features.
- If it is feasible, I encourage attempting identification in the field. If multiple specimens can be found, feel free to sit down with a specimen and A Utah Flora and work on it. But still take multiple specimens for later verification in the herbarium and for voucher specimens.
- Be sure to show the new specimen to the whole crew in order to assure that the species does not already have a code or that someone else does not know

the species. This will also allow everyone to learn the new species as well as its code.

A note on oak:

Due to oak's complicated underground rooting systems, it is impossible to determine what an individual is without involved (and expensive) DNA analyses. Additionally, due to the many shoots oak produces, we will not be counting stems. The only measurements that will take place on oak are cover estimates in the form of percentage cover for the density and cover subplots and the shrub transects for overall plot cover.

Appendix C. Study 2 Germination Protocols

Once back at NAU, seeds will be randomly chosen by taking a small handful from the envelope without looking at it. 200 seeds will be counted from each bag, 100 of these will be randomly selected and placed in a separate paper envelope to dry while the other 100 will be divided into four groups of 25 seeds.

Each group of seeds will be placed on two pieces of evenly moistened filter paper in a petri dish labeled with the plot information.

All of the petri dishes will be placed in a growth chamber set on 20°C night and 30°C day and a relative humidity of 75% until no seeds germinate for two weeks.

Placement of petri dishes in growth chamber:

One dish from each plot will be placed on each shelf.

To determine where on each shelf a dish is placed, plot numbers will be randomly selected from written pieces of paper. The location will start in the left rear of the growth chamber shelf and will continue towards the front. Then next column will then start at the back of the growth chamber and continue forwards placing petri dishes in this order until all petri dishes are on the shelf.

This randomization will occur separately for each shelf in order to assure that not all petri dishes from plot P-12-T are in the left rear corner of the chamber

Filter paper will be checked every other day for continued moisture, and more water added to the filter paper if necessary.

Seeds will be assessed every 2 days in order to determine germination. Seeds will be considered germinated, and therefore viable, when the 79adical is greater than or equal to 2 mm.

Germinated seeds will be removed from the petri dish as they are counted.

Appendix D. Data Collection Summaries

Spring 2008:

PJ Plots

- Sampled: May 8-May 13, 2008 (sampled early)
- All plots were sampled
- Line transect was not performed for Gambel oak cover

GO Plots

- Sampled: May 22-May 26, 2008 (sampled early)
- All plots were sampled

Fall 2008:

PJ Plots

- Sampled: October 2-October 6, 2008 (sampled late & after very large precipitation event that could have washed away vegetation)
- Pair 5 dropped from sampling due to low CBI severity rating

GO Plots

- Sampled: October 16-October 20, 2008 (sampled late)

Spring 2009

PJ Plots

- Sampled: May 14-May 16, 2009

GO Plots

- Sampled: May 16-May 18, 2009
- Pair 5 and 9 dropped from sampling due to steep slopes and danger to crewmembers

Fall 2009

PJ Plots

- Sampled: October 13-October 15, 2009

GO Plots

- Sampled: October 10-October 13, 2009

Spring 2010

PJ Plots

- Sampled: May 17-May 21, 2010

- Only richness and biomass were sampled due to time restrictions involved with completing deliverables on time

GO Plots

- Sampled: May 21-May 25, 2010
- Only richness and biomass were sampled due to time restrictions involved with completing deliverables on time

Appendix E. Summary of Deliverables and File Locations

Deliverable Description	Date Completed	File Location
Effectiveness monitoring sampling design and protocols as a monitoring plan	Included in Final Report	FinalProjectDocumentation/Protocols
Progress report	2/2008, 4/2009	FinalProjectDocumentation/Presentations
Presentation to park staff	2/2008, 4/2009	FinalProjectDocumentation/Presentations
Annual report	Summary sheets provided to parks staff during above presentations; annual permit reporting completed.	FinalProjectDocumentation/Presentations
Draft final report to the park with at least 1 month for the park to review and comment, and time for the Principal Investigator to incorporate comments	Draft to Zion 7/4/2010	FinalProjectDocumentation/Reports/Garmoe_2010DRAFTFinalReport.docx
Final report	9/1/2010	FinalProjectDocumentation/Reports/Garmoe_2010FinalReport.pdf
Final presentation	Planned for 10/2010	
Brief report abstract suitable for public distribution and two hard copies and an electronic version (in PDF file format) of the final report and mail to the NPS Research Coordinator, CPCESU, NAU, P.O. Box 5765, Flagstaff, AZ 86011-5765	After USGS pending review	

Presentation at a regional or national BAER meeting	AFE Georgia Fire Conference 11/30/09-12/04/09	FinalProjectDocumentation/Presentations/2009_Presentation-AssociationFireEcology-FireAsAGlobalProcess.ppt
Presentation at a regional or national scientific conference	IAWF Yellowstone Fire Conference 9/23/08-9/26/08; Wildfire and Invasive Plants in American Deserts Conference and Workshop,12/9/2009-12/11/2009; AFE Georgia Fire Conference 11/30/09-12/04/09	FinalProjectDocumentation/Presentations
Color Country presentation	2/2008, 4/2009	FinalProjectDocumentation/Presentations/2008_ZionUpdateMeeting.ppt
Publishable paper for peer-reviewed scientific journal	Expected 9/2010	
All databases, GIS data layers, and photos from the project with Park and FDGC compliant metadata	9/1/2010	FinalProjectDocumentation/Database/DakotaHillDatabase.mdb, FinalProjectDocumentation/GISLayers, FinalProjectDocumentation/Pictures
Thesis	4/26/2010	FinalProjectDocumentation/Reports/Garmoe_2010Thesis.pdf
Plant Photo Guide	9/1/2010	FinalProjectDocumentation/PlantGuide/DakotaHillPlantGuide.docx
Working plant collection	9/1/2010	FinalProjectDocumentation/Herbarium/WorkingCollectionPlantList.xlsx