Treatment Effectiveness Monitoring for the Kolob Fire Burned Area Rehabilitation Treatments

Final
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Abstract

In June of 2006, the Kolob fire burned 4252 hectares within Zion National Park, making it the largest fire in the history of the park. Invasive bromes (non-native annual grasses) were known to occur in 70% of pre-fire plots within the burn, causing concern that the post-fire reestablishment of the native plant community would be inhibited. In addition, an increase in post-fire brome abundance would likely increase the frequency of future fires to atypical levels, creating an invasive grass-fire cycle. The Burned Area Emergency Response (BAER) team, in conjunction with Zion National Park staff, determined that aerial application of herbicide would be essential to reduce brome abundance and thus provide the native species time to reestablish. One area within the fire had been heavily invaded by bromes pre-fire. In this area, both an application of herbicide and seeding with native perennials were prescribed since the native seedbank was likely diminished. We therefore tested the hypotheses that a) herbicide would decrease brome abundance and b) the addition of native seed coupled with herbicide would decrease brome abundance while facilitating greater establishment of the seeded native species. Three sites were established within the burned area to determine the effects of herbicide and seeding on brome abundance: two sites examining the effects of herbicide, and one site examining the effects of herbicide, seeding, and a combination of herbicide plus seeding. We found that herbicide application is effective in reducing brome abundance even the second year following treatment. We found that although herbicide negatively affected the abundance of the seeded native species, when seeding was coupled with herbicide the combined effect on brome abundance was greater than herbicide alone. We also found that fall application of herbicide, even after germination has occurred, was still effective at decreasing brome abundance. However, if the management objective is to balance decreasing brome (via herbicide) while increasing natives (via seeding), the preliminary data presented here on seeded species abundance suggests that this goal may not be met because the seeded species were negatively affected by herbicide. Nonetheless one native species, *Sporobolus*, had comparatively large biomass by the second year suggesting that this species may have great potential as a restoration species.

1 Introduction

Fire frequencies have increased dramatically in the intermountain West following the introduction of *Bromus tectorum* L. (cheatgrass) and *Bromus rubens* L. (red brome) (hereafter bromes), two non-native annual grasses from Eurasia. In pinyon-juniper woodlands, fire rotations have been estimated at 400+ years (Romme et al. 2004), but there is general consensus that fire frequencies have increased in this vegetation type (Monson 1992; Gruell 1999). Introduced bromes do not require disturbance to invade pinyon-juniper woodlands because of wide spacing between native shrubs and grasses (Floyd et al. 2000). Bromes fill in these intershrub spaces and senesce earlier than native annual plants, creating a continuous layer of fine fuels that burns more frequently than the historical fire regime for this vegetation type (Monson 1992). In a post-fire scenario, bromes have further competitive advantage because fire tends to cause high mortality in mature pinyon pine and juniper species, and neither species resprouts or stores a persistent seedbank. This grass-fire cycle can cause a vegetation type conversion on a landscape scale, decreasing diversity and ecosystem integrity (D'Antonio and Vitousek 1992; Brooks et al. 2004). In addition to the increased fire frequencies in brome-dominated systems, there is generally very slow to negligible recovery of natives following fire (e.g. Turner 1971, West 1979, Haubensak et al. 2009), which has likely contributed to the conversion of native shrubland and woodland to non-native annual grassland in a sizeable area of the region (Whisenant, 1990). Decreasing the abundance of the bromes while increasing that of native species is therefore a management goal.

In Zion National Park (Zion), major efforts are underway to manage non-native species. A collaborative effort between Zion and several researchers has resulted in multiple experiments aimed at controlling bromes following fire. These small-scale experiments used prescribed burns, followed by imazapic (Plateau®) herbicide and native seed application, to reduce brome abundance and increase native plant species (O'Neil 2008; Dela Cruz 2009; Matchett et al. 2009). The timing of herbicide application was found to be most effective in the fall following burning.

In 2006, the Kolob Fire burned a total of 7135 hectares, 4252 of which were within the park. The fire burned across an elevation range of 1100-2100 m. The pinyon-juniper vegetation type, which comprised 75% of the area, burned as a high mortality crown-fire and opened the landscape to further invasion by bromes. In addition, bromes were found in trace amounts in 70% of plots visited within the burned area during a pre-fire vegetation mapping effort (Kolob Fire Emergency Stabilization and Burned Area Rehabilitation Plan, 2006). The previous research done at smaller-scales was instrumental in formulating a large-scale rehabilitation and restoration plan following the Kolob Fire.

Given the likelihood of a post-fire type conversion a Burned Area Emergency Rehabilitation (BAER) team and park staff proposed aggressive measures to protect existing plant communities and restore native vegetation within the burned area. Several treatments were identified as part of the Kolob Fire BAER plan to decrease invasive bromes and promote recovery of native species following fire (Figure 1.1). The preferred treatment was aerial herbicide spraying on 3422 burned hectares within the park. In addition, aerial seeding of native species was applied to 192 hectares along the Kolob Terrace Road in the northern part of the fire. The monitoring component of the plan (reported here) was designed to look at the effectiveness of both the aerial herbicide and seeding treatments to decrease brome abundance and increase native species abundance.

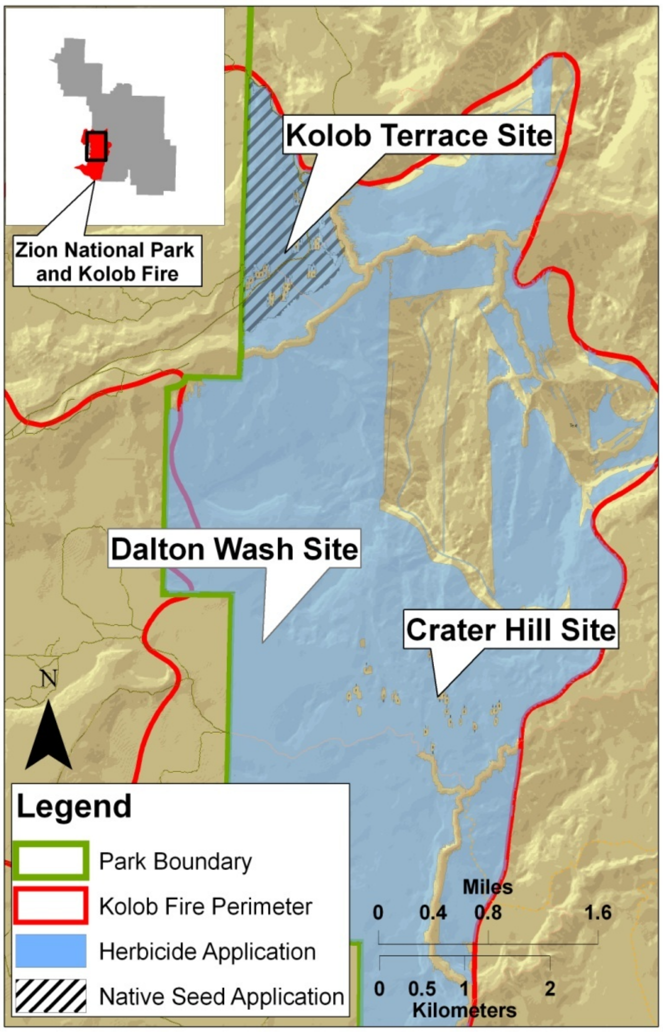

Figure 1.1 Treatments and study sites. Overview of the three study sites established to monitor the efficacy of BAER treatments at controlling post-fire brome populations within the 2006 Kolob Fire, Zion National Park. The 3422 burned hectares that received an aerial application of imazapic herbicide are shown in blue. An additional 192 hectares also received native seed treatment of four perennial species, which is represented by diagonal lines at the Kolob Terrace Road site.

1.1 Objectives & Hypotheses

The general objectives of this project were:

- To develop a plan with Zion National Park staff to monitor the effectiveness of the herbicide and seeding treatments as prescribed by BAER and Zion National Park within the Kolob Fire Area.
- To locate suitable sampling sites including the designation of untreated controls;
- To implement the monitoring plan, collect and analyze data, communicate results to park and other interested parties through reports, presentations and peer-reviewed publications.

We tested the following hypotheses:

1. Application of herbicide will decrease total brome density, percent cover, and biomass;
2. Application of herbicide coupled with seeding of native species will both decrease brome abundance (density, percent cover and biomass) and as a consequence, allow seeded native species abundance (density and biomass) to increase;
3. Application of seed from four native species will increase abundance of these seeded species (density and biomass).

In addition to these hypotheses, we also addressed the following questions that were of specific interest to the park:

4. Did the late application of herbicide result in smaller mass per individual plant (i.e., stunted plants) compared to control, as was observed by park staff and researchers in some of the treated areas?
5. How well does percent cover of brome predict its density? Biomass?

1.2 Kolob and Dakota Hills Linked Research

This report summarizes one component of post-fire restoration research underway in Zion. This report addresses the brome response to the herbicide and seeding treatments at three different sites in the Kolob fire in 2007 and 2008. Additional funding was secured through the Joint Fire Science Program (JFSP) in 2007 to assess the treatment effects on the entire understory plant community (in addition to the seeded species mentioned in this report) and the entire seedbank community following the Kolob fire. The final publications from the Kolob fire will cover 2007-2010 for the understory community and 2006-2009 for the seedbank data. This report does not include the seedbank response, and only includes the response of the understory species that were added to plots as the seeding treatment (referred to as the seeded species).

In addition to the above-mentioned research on the Kolob fire, research is being done on the 2007 Dakota Hills Complex. This fire burned 3,700 ha with approximately 2,400 ha in Zion. The BAER team and park staff decided to spray herbicide across approximately 1200 ha in the Dakota Hills Complex. The research team in the Thode lab at NAU again joined forces with USGS, BAER and Zion to assess the impacts of the post-fire herbicide spray on the entire plant community and a viability study was done to look at the effects of herbicide on germination rates of bromes.

To summarize, additional research objectives include examination of the effects of post-fire treatments on 1) the plant community seedbank (Kolob fire; Brisbin, Thode and Brooks); 2) brome abundance and plant community composition (Kolob Fire and Dakota Hills fire; Thode, Weber, Haubensak and Brooks; and Garmoe, Thode and Hunter); and 3) brome seed viability (Dakota Hills fire; Garmoe, Thode and Hunter).

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

2 Methods

2.1 Study Area Description

In late June 2006, the Kolob Fire was ignited in the southwestern corner of Zion National Park (Figure 1.1), burning 7135 ha, over 4252 ha within the park. Pre-burn vegetation consisted mainly of pinyon-juniper woodland (*Pinus monophylla* Torr. & Frém. and *Juniperus osteosperma* [Torr.] Little) with an estimated 17% shrubland and grassland communities. In the fall following the fire, three sites were located within the burn perimeter (Figure 1.1 and Table 2.1). Two sites were located in pinyon-juniper woodlands; one site was located in grass/shrubland. The three study sites ranged in elevation from 1290m to 1500m (Table 2.1). Average total annual precipitation in this area is 392 mm, with the majority of precipitation falling between October and April and about 20% falling as monsoonal precipitation between July and September (Figure 2.1). However, monsoonal patterns are not reliable from year to year in this area. Average annual temperature is 16.2 °C. Both 2007 and 2008 were warmer than average and had 75 mm less annual precipitation (20% below average). Monsoonal precipitation in 2006 (which likely influenced the brome cohort measured in spring 2007) was 14% above average while 2007 was 41% above average (which influenced the cohort in spring 2008). The soils in these sites are derived from sandstone, have low salinity, neutral pH and mostly sandy texture (Harper et al. 2003).

Table 2.1. Study site characteristics

Site	Treatment	UTM	Vegetation	Geologic Grouping	Elevation (m)	Associated Species
Kolob Terrace	Herbicide & seeding	E313733 N4127091	Pinyon-juniper	Cinder basalt	1340-1500	Red stem stork's bill (*Erodium cicutarium*); Rattlesnake weed (*Chamaesyce albomarginata*); Broom snakeweed (*Gutierrezia saothrae*); Prickly-pear (*Opuntia spp.)*
Crater Hill	Herbicide	E315300 N4121873	Pinyon-juniper	Talus	1290-1420	Galleta grass (*Pleuraphis jamesii*); Desert marigold (*Baileya multiradiata*); Penstemon spp. (*P. eatonii, P. pachyphyllus, P. plarneri*); legumes (*Psorothamnus fremontii, Dalea searlsiae*)
Dalton Wash	Herbicide	E313300 N4125568	Grass/ shrubland	Alluvium -eolian	1350-1380	Galleta grass (*Pleuraphis jamesii*); European bindweed (*Convolvulus arvensis*); Thompson's peteria (*Peteria thompsonae*); Red stem stork's bill (*Erodium cicutarium*); Rattlesnake weed (*Chamaesyce albomarginata*);

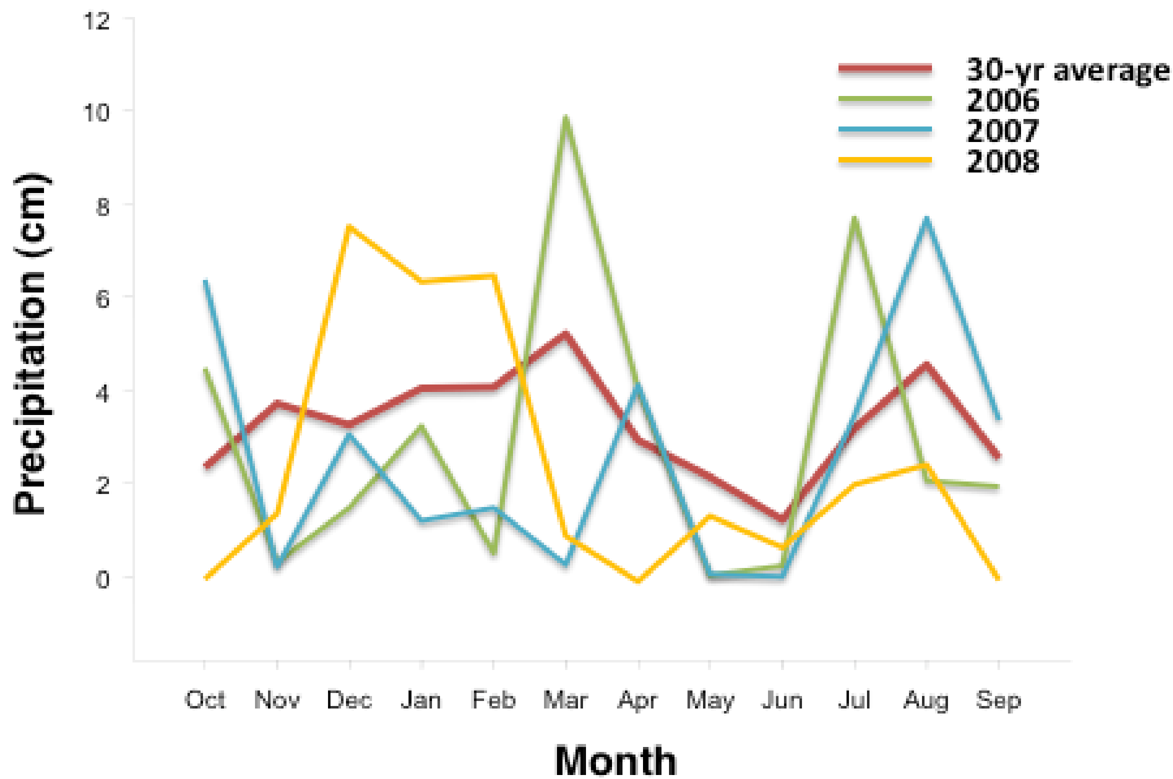

Figure 2.1 Monthly precipitation in 2006, 2007 and 2008 along with 30 year average at Zion National Park, Washington Co., Utah.

2.2 Treatments

Between 28 October and 6 November 2006, 3422 burned hectares received an aerial application of imazapic (Plateau®) herbicide. The herbicide was applied via helicopter because of the large area and difficult terrain to be treated. The application rate was 0.59 L/ha (8.1 oz/acre) of imazapic, combined with the surfactant Liberate. The manufacturer's recommendations were to apply the herbicide before brome germinates. Because of the time required to complete the National Environmental Policy Act (NEPA) planning process, the herbicide application did not begin until after cheatgrass and red brome emergence.

Imazapic can affect both annuals and perennials (to a lesser extent) due to its particular mechanism of inhibition (Vollmer and Vollmer 2008). Although non-target effects of this herbicide are poorly documented, some research has shown that its application can decrease cover of native grasses and forbs by up to 80% in Wyoming sagebrush where cheatgrass control was the primary goal (Baker et al. 2009).

One site was also seeded with native species because of concerns about high pre-fire amounts of brome around the ignition area (Figure 1.1). On November 1 and 2, 2006, 193 hectares at Kolob Terrace received an aerial application of native seed at 9.1kg/ha. The seed mix included bottlebrush squirreltail (*Elymus elymoides* [Raf] Swezey), sand dropseed (*Sporobolus cryptandrus* [Torr.] A. Gray), scarlet globemallow (*Sphaeralcea coccinea* Nutt.) and Rydband Palmer penstemon (*Penstemon palmeri* A. Gray).

2.3 Experimental design

In order to select study sites, we first stratified the burn area by treatment type, immediate post-fire burn severity, vegetation type and geologic grouping. Treatment type refers to the application of herbicide and native seed (Figure 1.1). Immediate post-fire BAER burn severity maps were used to delineate areas with high burn severity as those were the sites the park was targeting for treatment. Within these high burn severity areas, we chose study sites within vegetation types and geologic groupings that best represented the park. Thus, we located two study sites in pinyon-juniper woodlands, and one site in grassland/shrubland (Table 2.1).

2.3.1 Kolob Terrace

At Kolob Terrace the effects of herbicide and native seed addition on brome response were tested in a randomized complete block design with 11 blocks (Table 2.2 and Figure 2.2). Each block contained four plots with one of each of the following treatments: 1) untreated control, (2) seeding only, (3) herbicide only and (4) seeding plus herbicide. We buffered plots by 15 m on all sides to facilitate accurate application of treatments, with a minimum distance of 15 m from roads and 30 m from each other (Figure 2.3). Due to the size and type of the seeding boom, the helicopters were unable to accurately seed our plots so hand-seeding was used at a rate consistent to the aerial application on November 5, 2006 (Figure 2.4). Herbicide was applied via helicopter, and controls and seed only treatments were skipped using GPS locations of the plots.

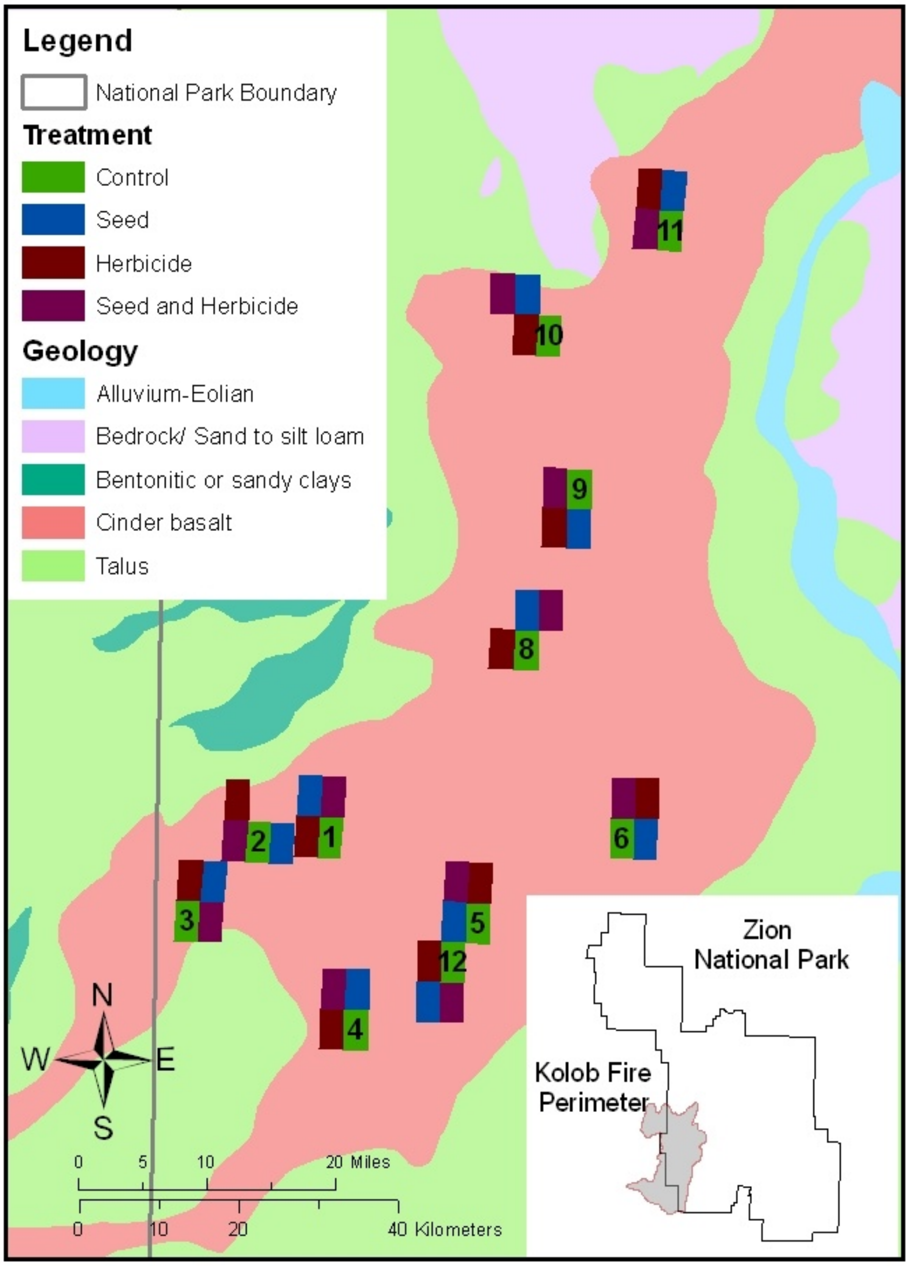

Figure 2.2 Map of the randomized block design layout at Kolob Terrace. The grouped geology stratification layer is shown. Block 7 was dropped from the analysis due to inaccurate application of the herbicide, leaving 11 blocks total.

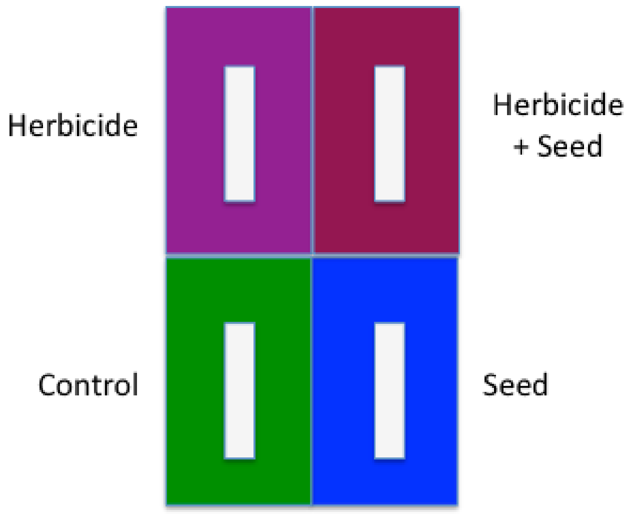

Figure 2.3 Plot and block layout for Kolob Terrace showing 5x30 meter belts within buffer zones (15 meters on each side of belt) for each treatment arranged in a block design. Treatments were randomly assigned to each block.

Figure 2.4 Preparing seed bags at Kolob Terrace for hand seeding of plots

2.3.2 Dalton Wash and Crater Hill

At Dalton Wash and Crater Hill the effect of herbicide on brome response was tested in a paired design since there was no seeding treatment at either of these sites. Because Dalton Wash was a shrubland/grassland, we established a different plot configuration than at Kolob Terrace and Crater Hill, both of which were pinyon-juniper sites. At Dalton Wash, we established 30 paired plots of 2 x 2 m with a 1 m buffer around each plot. Each pair consisted of one untreated control and one plot treated with herbicide (Figure 2.5). Because the vegetation was low-statured here (no trees or large shrubs), we were able to cover each control plot with six millimeter polyethylene sheeting cut to 4 x 4 m squares to ensure they were not sprayed with herbicide (Figure 2.6). The Crater Hill site had 13 paired plots of 5 x 30 m and was buffered in the same manner as the Kolob Terrace site (15m on all sides with 30m between pairs, Figure 2.7). As at Kolob Terrace, plots at Crater Hill not receiving herbicide (control) were skipped by the helicopter using GPS locations.

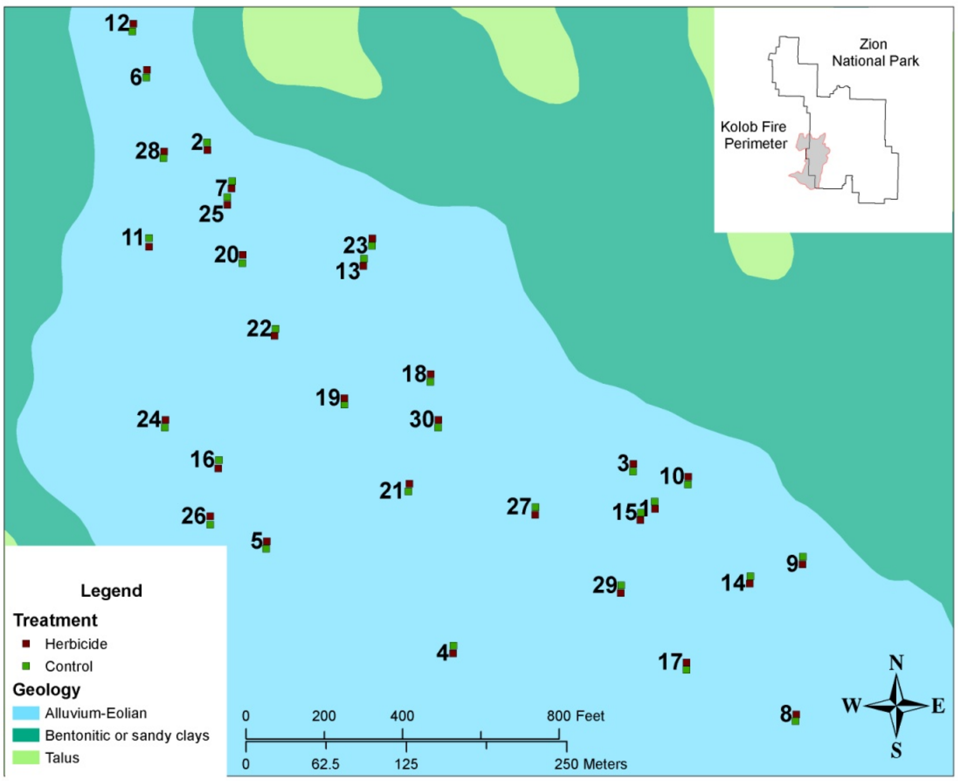

Figure 2.5 Paired plots at Dalton Wash site. The grouped geology stratification layer is shown. Treatments were randomly assigned to pairs.

Figure 2.6 Polyethylene sheeting covering control plots at Dalton Wash

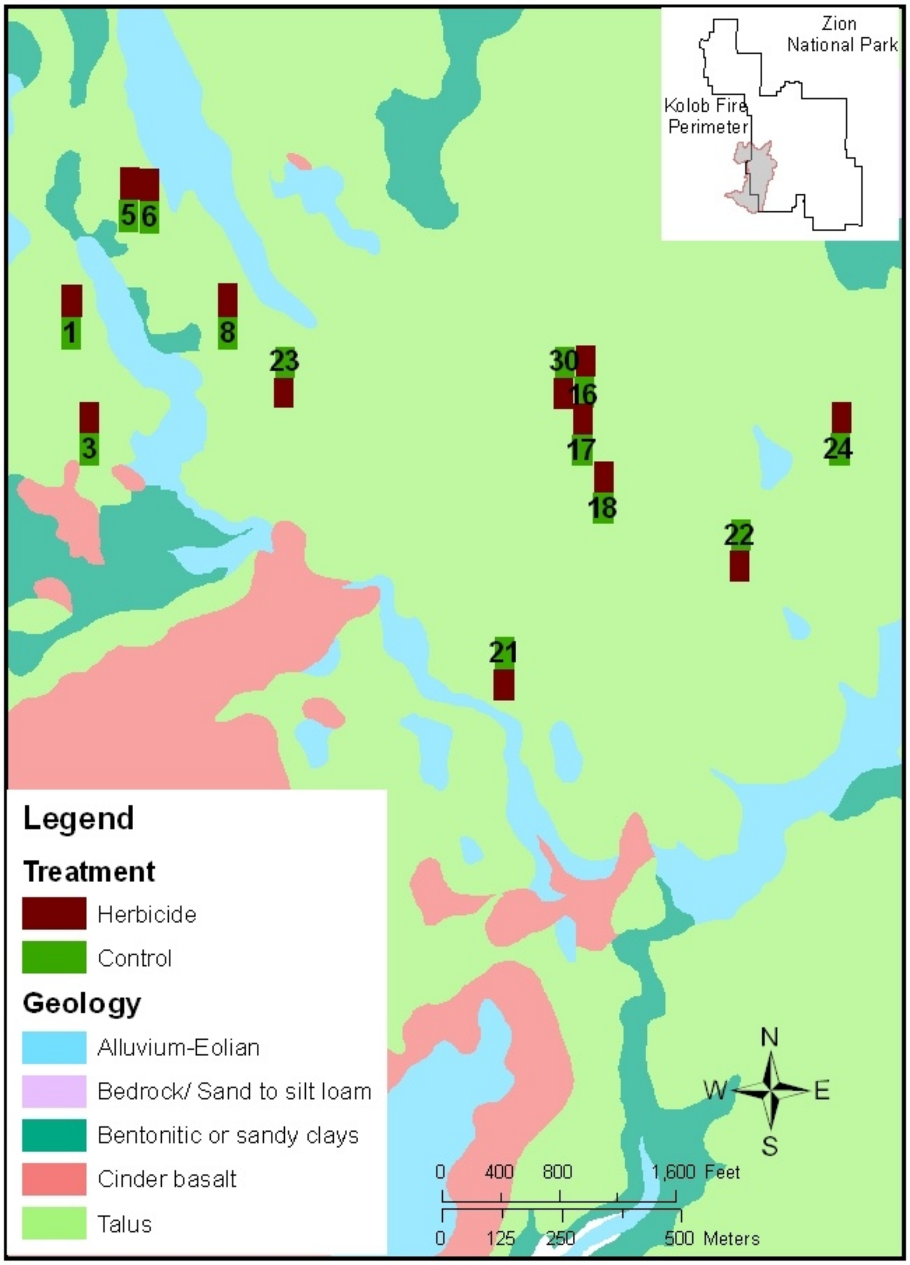

Figure 2.7 Paired plots at Crater Hill site. The grouped geology stratification layer is shown. Treatments were randomly assigned to pairs.

2.3.3 Loss of Plots within Blocks (or replicates)

Because of operator error, some of the herbicide treatments were applied outside of treatment boundaries and therefore compromised a number of subsampling points (subplots) within plots. This only occurred at Kolob Terrace and Crater Hill. We defined subplots as compromised if they were within 5 m of the herbicide spray (GIS data provided by Zion park staff) and removed those subplots from analyses. This resulted in unequal subplot numbers within each plot (Table 2.2). In one case at Kolob Terrace, all plots within a block were compromised so the entire block was removed from analysis (Table 2.2). No plots at Dalton Wash were compromised because plastic sheeting was used to protect control plots from herbicide spray. There were fewer subplots sampled from those plots because they had a different design (see Section 2.3.2). At Crater Hill, there were other (funding, staffing, erosion) constraints that caused small losses of subplots from plots, in some cases resulting in losses of plot pairs. See Appendix C for more details on why particular subsamples or replicates were dropped from analyses.

Table 2.2 Experimental design for study sites. Variability in number of subsamples reflects compromised treatments due to improper application of herbicide.

Site	Experimental Design	Plot Size	Replicates	Plots	Subsamples
Kolob Terrace Rd	Randomized complete block	5 x 30 m	11	44	3-5 density & cover; 1-5 biomass
Crater Hill	Paired by location	5 x 30 m	13	26	3-5 density & cover; 1-5 biomass
Dalton Wash	Paired by location	2 x 2 m	30	60	2 density & cover; 1 biomass

2.4 Sampling Methods

We measured three responses of aboveground brome to treatments: percent cover, density and biomass. These variables were measured at the three sites at six and eighteen months post-treatment (spring 2007 and 2008, respectively). We attempted to sample vegetation at peak phenology of cheatgrass and red brome, between 16 April-6 June, 2007 and 24 April-20 May, 2008. Therefore, all analyses of bromes were conducted on spring sampling collections. Due to funding constraints, the Crater Hill site did not have biomass data collected for spring 2007.

For sampling at Kolob Terrace and Crater Hill (the two pinyon-juniper sites), we used a 5x30 m brushbelt nested within a 30-m diameter circle, modified from the National Park

Service's Fire Monitoring Handbook (Figure 2.8). Biomass and density were collected from five nested 1 x 0.5m frames located along the eastern 30 m boundary; each year frames were shifted north 1 m due to destructive sampling. Because all biomass was removed from these frames each season, we required a new frame for the subsequent sampling season. Thus, the eastern half was divided into 0.25 x 1 m frames and one biomass sample was collected per season. We clipped all plants 1.5cm above the root collar, removed dead plant material and counted number of individuals. Plants were oven-dried for 48h at 70°C then weighed. Density and cover were sampled for all herbaceous plant species along the western 30 m boundary in five nested 1x1 m frames. For each species, we recorded density and made ocular estimates of percent cover. Here, only bromes are reported.

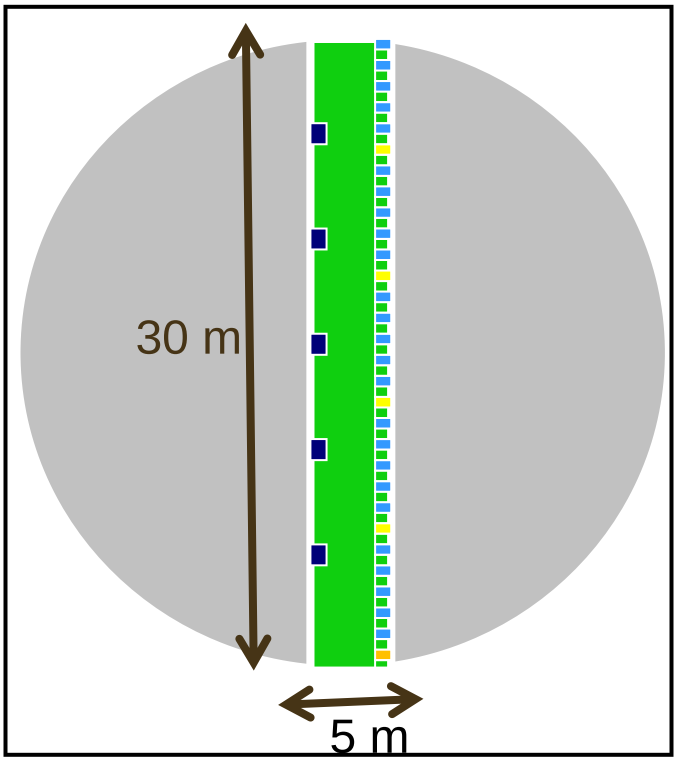

Figure 2.8. Plot design for Kolob Terrace and Crater Hill sites. Brome cover and density were measured in the sub-plots (frames) along the left side of the plot; biomass and density data were collected in sub-plots along the right side of the plot. Yellow frames represent the first year of destructive harvest; each subsequent year the sampled frame shifted 1 m north.

Plots at the Dalton Wash site were 2x2 m (Figure 2.9). Because this site was a shrubland/grassland, a different plot configuration was deemed appropriate for sampling. Additionally, because the park did not have fire monitoring plots in this type, we were less concerned about matching the Fire Monitoring Handbook (FMH) plot layout. We sampled density and cover by species along the western boundary in two 1x1 m frames. The eastern half was divided into six 0.25 x 1 m frames and one biomass sample was collected per season (Figure 2.9).

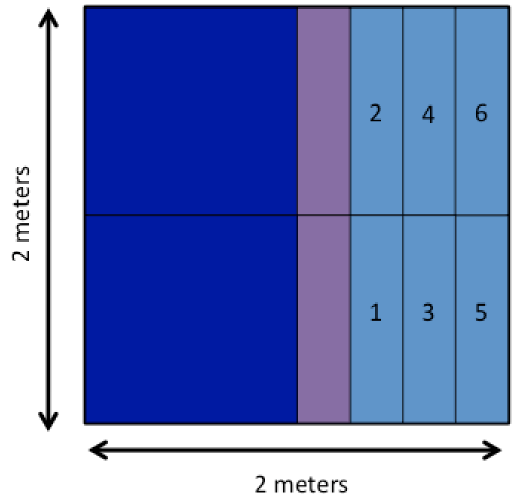

Figure 2.9. Plot design for Dalton Wash site.

There were several extenuating circumstances that may affect the interpretation of our results. In brief, areas were inadvertently grazed by cattle at Kolob Terrace due to fence disrepair. We developed an index of evidence of grazing, and found that grazing occurred evenly across all blocks. At Dalton Wash there was evidence that plots had been placed in areas that contained a pasture at some point in the past (Figure 2.10). However, all pairs were either within or outside the pasture.

Figure 2.10 Possible evidence of pasture through the middle of the Dalton Wash sampling site. Note denuded site on the right side of the picture.

2.5 Statistical Methods

The three study sites were analyzed as three separate experiments. Due to non-normal data, we conducted permutation-based multivariate analysis of variance (PerMANOVA, Anderson 2001) in PC-ORD software (version 5.20, McCune and Mefford, 1999). PerMANOVA has no distributional assumptions and can therefore be used on data that do not meet assumptions of normality required for ANOVA. The test statistic (pseudo-*F*) generated by PerMANOVA, however, is equivalent to the *F* statistic from a univariate ANOVA. We chose a priori to use 9999 permutations and $\alpha=0.05$. We analyzed all brome variables (percent cover, density, and biomass) separately to test the effect of herbicide and seed treatments, in both 2007 and 2008. Only spring sampling collections were analyzed because that time period represents peak phenology for brome. We used post-hoc pairwise comparisons to separate means.

We additionally analyzed the biomass and density of the four seeded species at the Kolob Terrace site where they were seeded. For this analysis, all four species were aggregated and analyzed as one group. Again, we used PerMANOVA to evaluate treatment effects (herbicide and seeding) on the composite seeded species group, in both 2007 and 2008.

We used regression analysis to examine the relationship between percent cover and both biomass and density in order to determine how well percent cover predicts the other measures of brome abundance. We only analyzed control plots, and examined each site and year separately. The objective of this analysis was to gain insight for the park's fire monitoring program to determine whether cover can substitute for biomass or density data. Typical sampling for the fire monitoring program will be in post-fire areas that have had no additional treatment (i.e., 'control' areas). The controls in this experiment represent those conditions. In addition, we had no reason to predict that the relationships between percent cover and either biomass or density would differ with treatment.

Because of compromised subplots (described in Section 2.2), there were unequal numbers of subplots within plots across treatments (Table 2.2). In only one case did this result in the complete loss of a plot (replicate) within a treatment (NAME THIS). All plots used in the analysis had no fewer than one subplot. Table 2.2 describes the number of replicates for the experiment at each site.

3 Results

Brome abundance was low across the three sites in the two years reported here, ranging from 30-80 individuals m^{-2} across the two years of sampling. Overall, herbicide application decreased brome abundance across sites, although the effect was less pronounced the second year following treatment (Figure 3.1). The effects were slightly different depending on which measure of brome abundance was evaluated. For example, brome cover did not always follow the same pattern as brome biomass or density. There was also inter-annual variability in brome abundance across sites obscuring any potential effect of herbicide. At Dalton Wash, for example, there was almost no detectable brome the second year following treatment even in untreated plots (Figure 3.1, panels g, h, and i). However, at Kolob Terrace the effect of seeding native species appeared to enhance the effect of herbicide in decreasing brome abundance (Figure 3.1, panels a, b, and c).

3.1 Kolob Terrace: Herbicide application and native seed additions

Six months after initial treatments, herbicide decreased both density and biomass of brome ($p < 0.05$ for both measures), whereas the addition of native seed alone did not result in a significant decrease in brome abundance. By 2008, in plots where both treatments were applied, there appeared to be an additive effect of seeding + herbicide resulting in even lower brome cover and biomass than with herbicide alone (Figure 3.1, panels a and c). Plots receiving seeding + herbicide had approximately 90% less brome density and biomass compared to control plots.

Adding seed alone, without herbicide, significantly increased the biomass of the four seeded species in 2007 (Figure 3.2). By 2008, only density of the seeded species was significantly greater in the plots where they were added compared to control plots. On the other hand, in plots where the four species were seeded plus herbicide was applied, these four species had significantly lower density and biomass compared to plots where they were seeded (Figure 3.2, 2008). Overall, these species had higher densities and lower biomass values in 2007, with lower densities and higher biomass by 2008, suggesting self-thinning with individuals growing larger by the second season. Most of the response of the seeded species was driven by sand dropseed.

3.2 Crater Hill: Herbicide only

At Crater Hill, herbicide spraying resulted in significantly lower biomass, density and cover. This effect persisted into the second year, where herbicide plots had approximately 50% the cover, density and biomass of control plots (Figure 3.1, panels d, e, and f). While this relative effect appears dramatic, brome absolute abundances were extremely low in general. For example, there were ~ 2 individuals m^{-2} in sprayed plots compared to ~20 individuals m^{-2} in the control plots. Likewise, percent cover in control plots was ~ 2% compared to ~1% in sprayed plots.

3.3 Dalton Wash: Herbicide only

At Dalton Wash, there was again a significant reduction in brome abundance with herbicide spraying (Figure 3.1, panels g, h, and i). However, in the second year of sampling there was virtually no brome that could be detected in this site altogether; therefore the effect of herbicide was not detectable the second year.

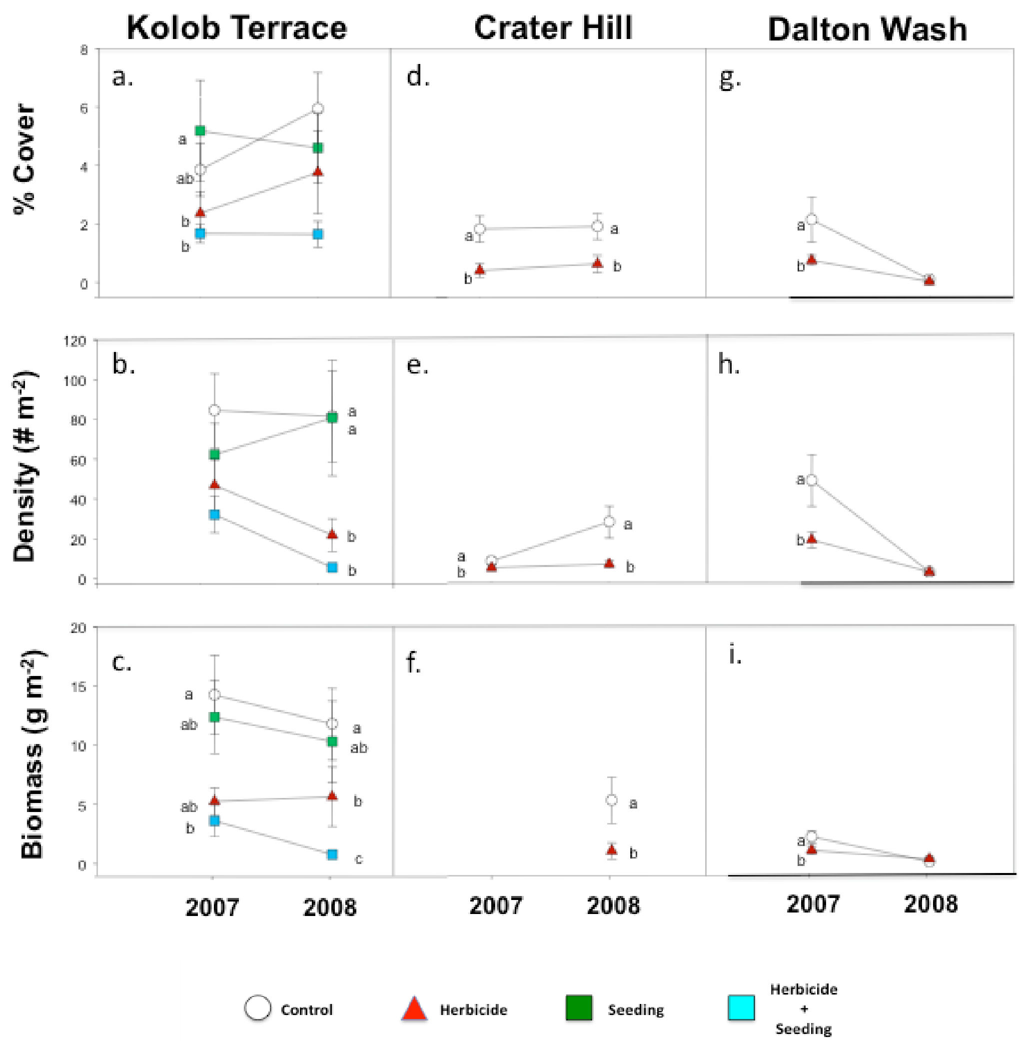

Figure 3.1 Average brome percent cover, density, and biomass across three study sites and two sampling seasons (2007 and 2008).

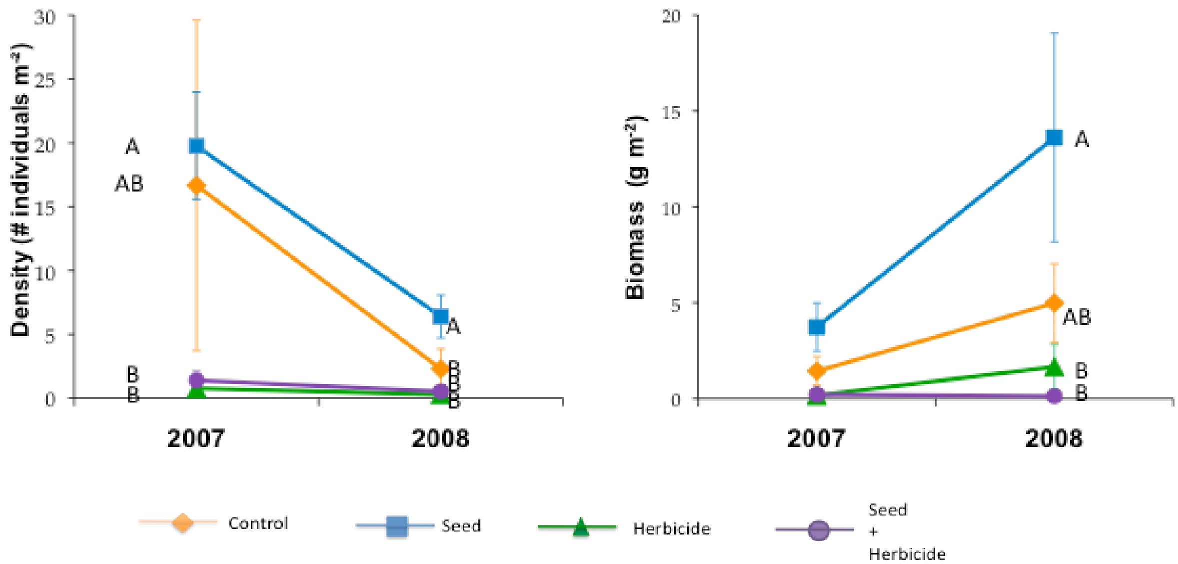

Figure 3.2 Total density and biomass of four seeded species (combined) to treatment at Kolob Terrace

3.4 Brome size (mass/plant) across sites and treatments

Only at Dalton Wash in 2007 was there a significant effect of herbicide on average individual brome size ($p = 0.005$). Brome plants in that site were significantly smaller in herbicide plots compared to control. In the two other sites, however, there were no treatment effects (either herbicide or seeding) on brome size in both years ($p > 0.05$) (data not shown).

3.5 Relationships between brome percent cover and other measures of abundance

Percent cover in general did not predict either density or biomass of brome across sites and years (Table 3.1). There were notable exceptions, however. At Crater Hill, for example, percent cover was significantly correlated with density in both 2007 and 2008 (r-squared = 0.233 and 0.498, respectively). At Kolob Terrace, percent cover was significantly correlated with biomass in 2007 (r-squared = 0.757). At Dalton Wash, percent cover significantly predicted density with a surprisingly high r-squared value (0.969). In general, however, we found no consistent relationship between percent cover and either density or biomass.

Table 3.1 R-squared values for percent cover versus density and biomass for brome across sites. Asterisks (*) indicate significant correlation at the 0.05 level.

	Percent Cover v Biomass	Percent Cover v Density
Kolob Terrace Rd		
2007	0.757*	0.015
2008	0.185	0.111
Crater Hill		
2007	a	0.233*
2008	0.040	0.498*
Dalton Wash		
2007	0.045	0.969*

a. Biomass was not collected at Crater Hill in 2007.

4 Discussion

4.1 What is the effect of herbicide application on brome abundance?

Our results suggest that while herbicide application is effective at reducing brome abundance, there is important site-to-site variation. At one pinyon-juniper site (Crater Hill), herbicide decreased brome abundance even two years after application. At the other pinyon-juniper site (Kolob Terrace), however, the effect of herbicide was dependent on what measure of abundance was used. For example, density of individuals decreased more with herbicide the second year, but biomass at the square meter level stayed the same even as biomass in control plots decreased the second year. We should also note that although we found that herbicide significantly reduced brome abundance, background levels of brome in these sites were very low to begin with.

Our results corroborate small-scale studies recently conducted in Zion Canyon, which showed that burning followed by fall application of herbicide resulted in reduced cover of brome (O'Neil 2008; Matchett et al. 2009). Those studies suggest that fall application of herbicide is most effective, in fact, when it follows burning as opposed to other methods of control like mowing, because mowing leaves litter biomass (Matchett et al. 2009).

Interannual variation in precipitation is an important determiner of brome abundance. In the second year of our study, for example, spring rains were much earlier than the previous year, and the late spring was very dry (Figure 2.1). Consequently, 2008 generally had lower brome abundance across sites compared to 2007. This year-to-year variation in precipitation has the potential to reduce the treatment effects. In particular, Dalton Wash had virtually no plants in 2008, and brome was no exception. This limited the ability to examine the treatment effects at this site.

There is a possibility that herbicide levels were lower around trees if they 'captured' some herbicide during aerial application by helicopter. However, because all plots were placed in high severity areas with similarly high density of trees (in the pinyon-juniper sites), we assume this effect to be the same across herbicide treatments. Thus we do not expect that the different herbicide treatments were differentially affected by this 'shading effect'. We acknowledge that this may have implications on the overall effectiveness of the herbicide spray, however we are unable to evaluate that in this study.

Even with relatively small sample sizes, we were able to detect treatment effects on brome and the seeded species. However, brome abundance was so low across all sites, that although we observed statistically significant effects of herbicide and seeding, we note that this may not be ecologically meaningful.

4.2 What is the effect of native species seeding on brome abundance?

Kolob Terrace was the only site that received native species seeding in addition to herbicide application. At this site, the effect of seeding appeared to almost double the negative effect of herbicide on brome abundance (Figure 3.1, panels a, b, and c), and this effect persisted through the second year of sampling.

These results are more dramatic than those reported by Matchett et al. (2009), who did not observe a strong effect of seeding on brome abundance in Zion Canyon. They speculated that several years may need to elapse before a significant effect of seeding would be detected, to allow those seeded species individuals to grow larger and exert a competitive influence. We do not have any way to assess whether the seeded species in our plots were competing for nutrients or water with brome. However, our data suggest that the seeded species in our plots were competing by taking up space that would otherwise be occupied by brome. This is despite the fact that the herbicide did heavily affect the four seeded species (see section 4.3).

4.3 What were the responses of the four seeded species?

As indicated in Section 2.2, the four seeded species were bottlebrush squirreltail, sand dropseed, scarlet globemallow, and Rydband Palmer penstemon. These species did occur in control plots (Figure 3.2) but had higher density and biomass when they were seeded. However, where the seeding was combined with herbicide, the seeded species showed very low density and biomass. This suggests that the seeded species were negatively affected by the herbicide.

However, Figure 3.2 shows that despite the fact that there were fewer individuals of the seeded species in 2008 compared to 2007, total biomass was over two times greater in 2008. This suggests that species that were able to seed or sprout post-fire and post-treatment had increased growth in 2008. In the winter of 2007-2008 (December-February), precipitation was above the 30-yr average (Figure 2.1), which likely favored native species growth. Conversely, the previous winter was below the 30-yr average with early spring rains. The increases in overall plant size of seeded species in 2008 could be both a time since fire and/or precipitation effect. We would like to note that the response of the seeded species was mainly driven by sand dropseed, underscoring the potential of this species in restoration efforts.

4.4 Was the delayed application of herbicide (after brome germination) still effective?

Observations were made by researchers and park staff in spring 2007 that herbicide application resulted in smaller brome individuals in the herbicide-treated area. However, this analysis suggests that such decreases only occurred at Dalton Wash in

2007. There was no variation in treatment (e.g., different time periods between emergence and herbicide application among sites) to explain these different outcomes. Overall, our results suggest that herbicide may potentially decrease the size of individual plants but more often decreases their percent cover, density, and biomass. These results suggest that even if the pre-emergent window for brome is missed in the fall, the application of imazapic is still effective. This recommendation is consistent with other studies that have resported effective fall application of herbicide in Zion (O'Neil 2008; Matchett et al. 2009).

4.5 How well does percent cover predict biomass or density of bromes?

In general, we did not find that percent cover could be reliably used to predict density or biomass of brome across sites or years. Although we examined these relationships in control or untreated plots only, these results are consistent with our observation that the three measures of abundance did not always respond similarly to herbicide or seeding. This result suggests that, for monitoring purposes in these vegetation types, there is not a reliable substitute for biomass.

4.6 Management implications and conclusions

- Herbicide application is effective in reducing brome abundance even the second year following treatment;
- Seeding of native species is only effective at reducing brome when coupled with herbicide;
- Fall application of herbicide, even after germination, was still effective at reducing brome abundance;
- Late application of herbicide did not generally decrease individual plant size with the exception of one site in one year (Dalton Wash, 2007). This was one exception out of a total of five site and year combinations;
- Although effects of treatments were persistent through the second year of sampling (2008), further observations from the following growing season (2009) suggest that treatment effects are decreasing at all sites. It is currently unclear how long the treatment effects on brome will last.
- If the management objective is to balance decreasing brome (with herbicide) while increasing natives (via seeding), the preliminary data presented here on seeded species abundance suggests that this goal may not be met. Specifically, we showed that the combined treatment had the lowest brome abundance, but the seeded native species were also negatively affected by herbicide.
- The increase in seeded species biomass from 2007 to 2008 was driven mainly by one species, Sand dropseed. We recommend this species be examined further for its promising restoration potential.

- The question remains: What cover of brome is required for fire to occur in this system? We found no consensus in the literature about a threshold level of brome cover below which restoration treatments would be considered successful in the pinyon-juniper type. Further research in this area is needed.

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Appendix A. Field Protocols

Kolob Terrace and Crater Hill Protocols (Spring 09)

Updated 3/04/08

Overview of KTR & CH

- Plot design is a modification of recommendations found in the NPS Fire Monitoring Handbook.
- Each Plot consists of a 5*30m brushbelt oriented North-South
- Each brushbelt has 2 rebar stakes per plot, each with a tag-- the green (or blue) stake marks the SW corner of the belt, the red (or pink) one marks the NW corner and is 30.3m due North. The SE and NE corners should have tent stakes in the ground 5m due East of the rebar. The rebar and their adjacent tent stakes mark out the boundary of each plot.
- **VERY IMPORTANT TO NOT WALK IN PLOT**—these plots will be sampled for 6 seasons and their integrity must be maintained.

KTR Design (Figure 1and 3)

- Area had both herbicide and native seeding
- 12 blocks comprised of 4 treatments—A, B, C, and D

    A—Untreated Control
    B—Native seeding only
    C—Herbicide sprayed only
    D—Seeded and herbicide sprayed

- Tags are labeled with a number on one side and with KTR-- PLOT#-- A, B, C, or D

CH Design (Figure 2)

- Area was only herbicide sprayed
- 23 paired plots of 2 treatments—T or U

    T- Treated with herbicide
    U- Untreated Control

- Tags are labeled with a number on one side and with CH—PLOT#-- T or U

Setting the belt up…..

- ➢ Run the meter tape out from the green/blue rebar due North 30.3m to the red/pink rebar.
- ➢ Should see nails in the ground marking the location of the five density frames. These will help guide you.
- ➢ TRY TO NOT THROW THE TAPE!!! When it is necessary, be sure to throw it to a place a few feet off the edge of the plot but around the object that is in your way.

- Run the second tape from the SE tent stake due North.
- Finish with the tapes running from the rebar to the tent stakes. You have now set up your 5*30m belt.

Remember to hold the tapes in towards the plot (on your right when pulling out the west tape and on your left when pulling out the east tape) so you **STAY OUT OF THE PLOT.

Multiple measures from one belt… (Figure 4)

1. **Pictures--** Minimum of four pictures for each plot. The purpose of these pictures is to document the vegetation changes within the plot year to year. Pictures should be taken in the following order EVERY TIME…
    - OV1: This is an overview shot of the plot taken from the mid-point of the southern boundary. Both 30m tapes should be in the picture.
    - 0-30m: Taken down the left tape and including the top of the green rebar.
    - 30-0m: Reverse side with top of red rebar in picture.
    - OV2: Overview of plot taken from the mid-point of the Northern boundary.
    - A photoboard will be provided and should have the following information: Location (i.e. KTR 1B), picture code (i.e. OV1), date and the photographer's initials.

**Occasionally, topography or an excess of trees/brush will necessitate taking additional pictures in order to achieve a full characterization.

2. **Density frames--** On western 30m tape.
   See troubleshooting guide for special cases.

    - Starting at 5m, place a 1*1m frame every 5 m for a total of 5 frames.
    - **Density--** every living herbaceous plant species with more than 50% root mass in the frame will be tallied.
    - **Cover estimates** are done by species (including shrubs) and estimates are to the nearest percentage (NOT with cover classes). Cover estimates are also recorded for rock, bare ground, and litter. Scorched earth will be recorded as a subset of bare ground. The total cover per frame may exceed 100%, due to overlapping species. However, each frame must have a cover estimate of 94% or above. If this is not the case, you will need to reevaluate your estimates.

**Cover estimates are done using the smoosh technique. Visualize the amt of aerial plant cover, remove the empty spaces and smoosh the rest together in your brain. That is your cover estimate.

3. **Richness--** The entire 5*30 m brushbelt will be used as a measure of species richness. All living species encountered within the belt are recorded including those in the biomass and density frames.

4. **Shrub density--** Each shrub with over 50% of its base rooted within the 5*30m brushbelt will be counted.

   - Record data by species, age class (immature/mature), whether it is living or dead, and tally the number of individuals within each entry.
   - Any changes in age, species, or livingness will result in a new entry. (i.e. Tally for adult OPUPHA live is different from tally for juvenile OPUPHA live.)

**When recording species richness and shrub density, it is sometimes necessary to walk through the plot. In this case, stay to the center of the plot and rock-hop.

5. **Biomass--** The biomass clip plots are located along the eastern 30m tape. 5 frames (measuring 1*0.5m) will be clipped with Frame 1 being the furthest South. The exact location of these frames will be provided prior to harvesting.

   - Plants are separated by species IN THE FIELD and placed into the appropriate size brown paper bags.
   - We will be clipping all plants at 1.5cm above ground level. If you pull up the whole plant**, YOU MUST CLIP THE ROOT/SEED OFF 1.5cm ABOVE THE COLLAR.**
   - All bags are to be labeled with plot info (KTR or CH-PLOT#-TREATMENT LETTER), date of collection, initials of collector, six letter code for species, the bag number for the frame (i.e.1/5) and # of specimens with final number circled
     ****Cards will be provided with required bag info****
   - We are only interested in this season's growth. Dead plant parts are to be separated and discarded.
   - Roll bag down twice (or as Hondo would say, fold it over twice) and staple shut and place in a laundry bag for easy transport.
   - Record the number of bags total taken per clip plot on the paper provided.

When you are leaving a plot….

- When reeling in tape, **DO NOT** stand at the red rebar and reel the tape in.
- Walk while reeling in line, a few feet away from the edge of the plot so that you are not causing undue distress to the plot.
- When come across an object blocking the way, step a few meters away from the plot and reel the tape up from there.
- Do not apply undue pressure to the tapes when reeling them up, as numerous ends have been snapped off in the past.

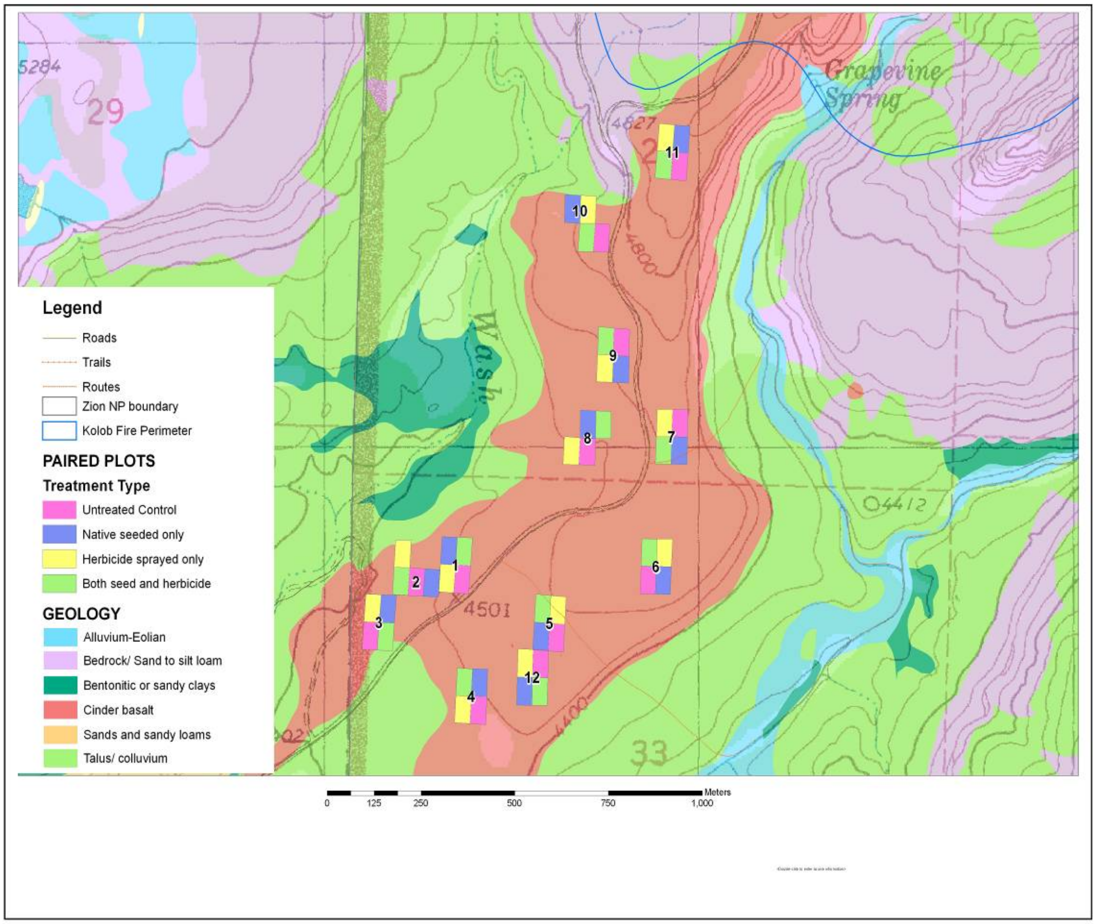

Figure 1. Within the area around the Kolob Terrace Road that received both aerial native seed spread and Plateau™ herbicide, there are twelve sampling blocks, each comprised of 4 plots. They are shown here over the geology layer.

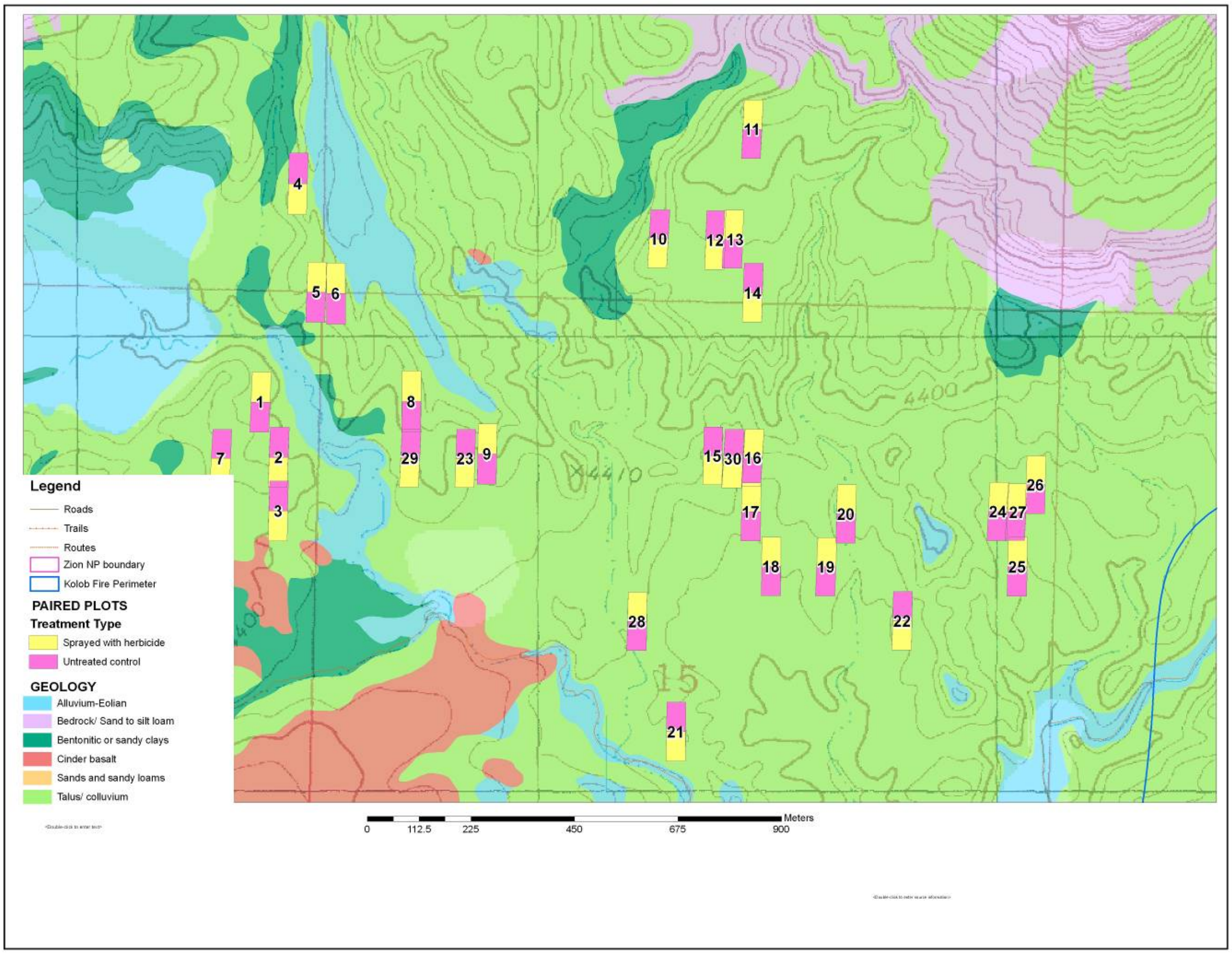

Figure 2. The Crater Hill site consists of 30 paired plots, with treatment type randomly assigned (shown here over the geology layer). We will only be sampling 23 of these pairs.

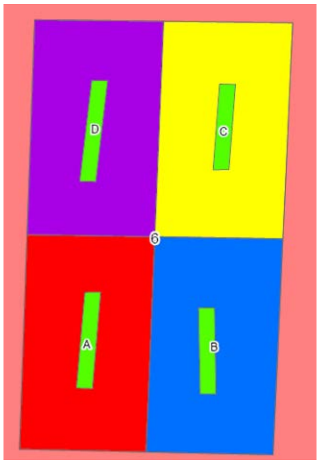

Figure 3. Close-up of KTR block 6. Each green rectangle represents the 5*30m brushbelt. The color areas around it represent the 15m buffers which were added to all sides to ensure treatment application.

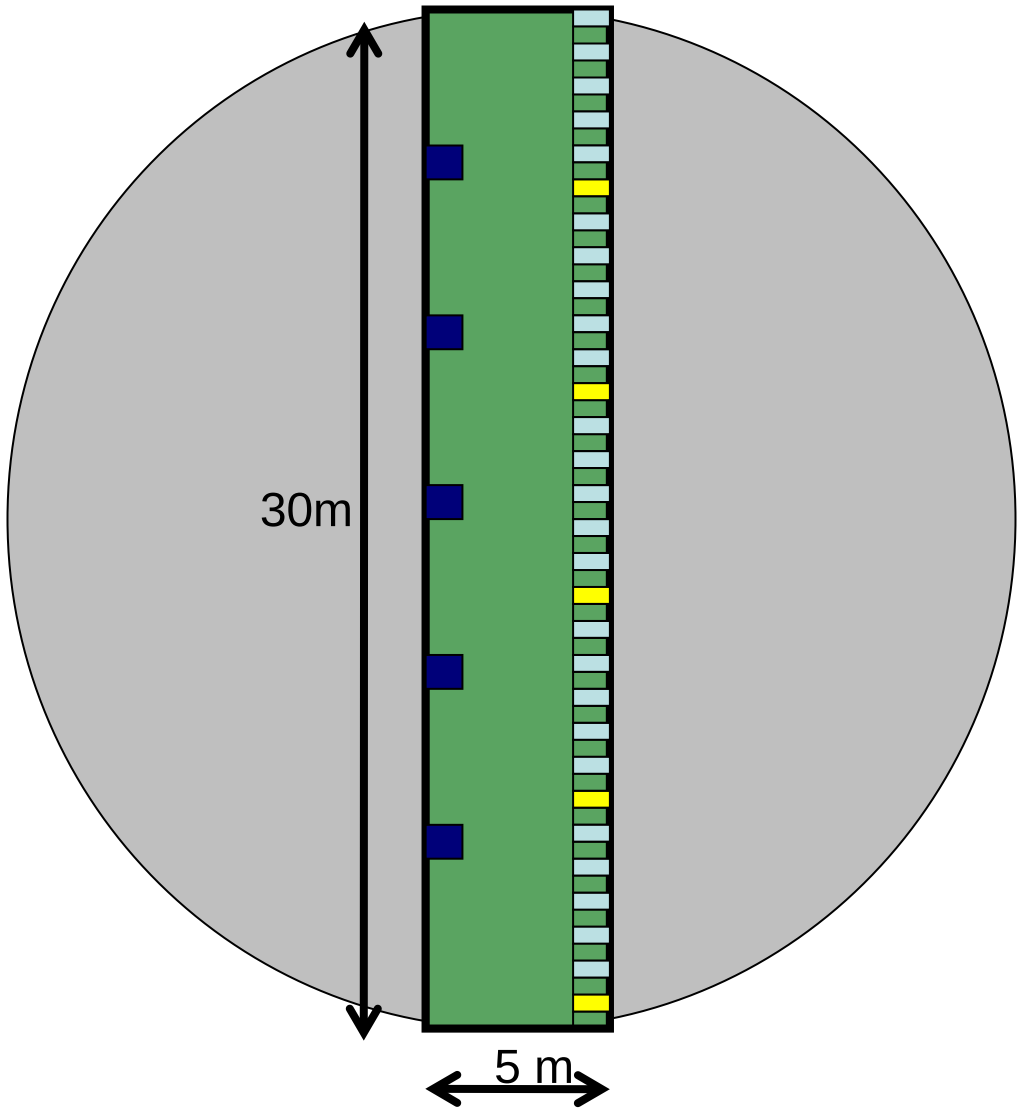

Figure 4. Drawing of an individual 5*30m brushbelt. The blue squares represent the density/cover frames which are located at 5m, 10m, 15m, 20m and 25m respectively. The smaller rectangles of the east side of plot indicate locations for the biomass frames. The yellow frames were sampled in the spring of 2007 and subsequent sampling will progress north so as to avoid sampling in same location each season. CBIs (30m circle plot) will not be repeated in the future. Design is for both KTR and CH.

Appendix B. Troubleshooting Guide for Cover, Density and Biomass Collection

Troubleshooting Guide
Updated 03/04/09

Cover

- When estimating cover, it is necessary to analyze cover from the stand point of whether or not it could support the growth of a brome. For example, if you encountered a bare rock it would be simply be classified as rock. However, if the rock had a depression filled with litter on top that was capable of supporting a brome seedling, then that portion would be classified as litter and only the remainder of the rock would actually be included in the rock estimate. **We estimate to the nearest percent.** The following is a description of the 7 cover classifications and instances where these classifications can be somewhat tricky:

    - <u>Vegetation</u> – 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 with the following stipulations: 1) we are only concerned with portions below 4.5 feet (Diameter at Breast Height) and 2) the foliage/branched creates an environment suitable for brome emergence below them (i.e. a severely burnt juniper branch with no needles or fine branches would not be included. The small amt of shade it provides would not create a favorable microclimate.) Overhanging branches that meet the above criteria would also be included.
    - <u>Rock</u> - Rocks are defined as being 2.5cm 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 will exceed 100 percent.
    - <u>Litter</u> **–** Litter consists of rocks smaller than 2.5cm, fallen needles and leaves, etc. A subset of this category is Coarse Woody Debris (CWD). This subset is defined as being any downed woody material that exceeds more than 1 percent of the entire frame. This percentage will be included in the overall litter estimate, but in the notes, it should be stated that the estimate includes X percent CWD. **This means the CWD estimate will always be less than the litter estimate.** Coarse Woody Debris can also include stumps (occupying more than 1 percent of the plot) if they are less than 1 foot tall. 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.

- Bareground – Very small, non-soil materials can be included in this category. ***Bareground is considered a harsh, inhospitable environment*** for bromes to grow in. This classification also has a subset for scorched earth, identified as blackened soil and/or the presence of powdery gray/white residues. As with CWD, all bareground will be lumped into one estimate but, a note should be made indicating how much is comprised of scorched earth. **Scorched earth estimates will always be less than bareground.**
- Bole – This classification is reserved for standing-dead trees and shrubs as well as solid stumps exceeding a height of 1 foot. Any individual matching the above criteria but occupying less than 1 percent of the plot, will be considered litter.
- Moss – The presence of moss is recorded if it comprises 1 percent or more of the total frame cover. *Lichens are not distinguished from their host substrate.
- Cryptogamic Crust – This classification is somewhat subjective. The fire killed many of the cryptogams, so they are often classified as litter. In some instances though, they are still very compact and their living status is 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. Otherwise they are considered litter.

Density

- Only living **herbaceous** 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 **-** (i.e. Pleuraphis jamesii, Penstemon palmerii)
    If two specimens are within 30cm of each other, they will be considered the same individual. Since they are rhizomatous, the 30cm measure is from any bunch within one individual.
  - Bunchgrasses - (i.e. Elymus elymoides, Sporobolus cryptandrus, Achnatherum hymenoides) If a distinct clump can be discerned then each clump will be counted as a single individual.
  - Bromes - (ie. Bromus tectorum, Bromus rubens)
    In SPRING seasons, NOT to be counted with single stem counts. Feel the root collar and count as clumps.
    IN FALL, each individual stem is counted as an individual.
  - Opuntia species - Counts will be based upon clumping and the numbers 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 individuals, if 2 plants are within .25m of each other, they are to be considered the same individual.

- Yuccas **-** There are relatively few yuccas in our research area. Therefore it should be very easy to distinguish individuals through a clumping technique.
- Amaranthus **-** Each stem is counted as an individual.
- Chamaesyce albomarginata **-** REMEMBER that individual shoots can form stolons and appear as new roots when it is the same individual.
- Portulaca oleracea **-**Individual stem counts.
- Lycium spp **-**If there are green leaves (either resprouts or on the stem) individual gets a cover estimate.

Biomass

- We collect biomass for herbaceous species only. This means biomass will not be taken from shrub species-- Opuntia and yucca species, Lycium, Quercus, Rhus, Purshia, Psorothamnus, etc. **WE DO COLLECT GUTSAR**.
- **EXCLUDING BROME AND ERODIUM**, when there are less than 10 seedlings (weighs less than.100 gram) in the frame, do NOT collect them. Add the information to the outside of another bag from the frame.
- **EXCLUDING BROME.** If there are 100s of individuals of one species in the frame, you can collect a percentage of the individuals in the frame and record on the bag the % collected. You must collect at least 75% of the frame (i.e. there are ~500 Erodium in one biomass frame, you may collect ~375 of them and write on the bag 75%).

Appendix C. Data Collection Summaries

Kolob Fire Data Collection per season:

SPRING 2007

1. Kolob Terrace Rd
    - Plots—1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12. Block 7 was later shown to be compromised due to inaccurate application and was removed from analysis.
    - Biomass, density and cover-- All 12 blocks and all subsamples for. Compromised subsamples later taken out of data.
    - Shrub density and richness-- All 12 blocks.
    - CBI- All 12 blocks
    - Pictures—All 12 blocks. Typically 4 pictures per plot.
    - Soil for nutrient analysis—10-20 cores were deposited into one sample and analyzed for Total N, Total C, available P, pH, Mn, Zn, and Fe.
2. Dalton Wash
    - Biomass, density and cover—All 30 pairs and all subsamples.
    - Pictures—1 per plot taken from the west
    - Soil for nutrient analysis—5-7 cores were deposited into one sample and analyzed for Total N, Total C, available P, pH, Mn, Zn, and Fe.
3. Crater Hill

******Time and temperature constraints on full sampling. Randomly chose 20 pairs to sample using random number chart******

- Plots—1, 2, 3, 4, 5, 6, 7, 8, 9, 16, 17, 18, 21, 22, 23, 24, 25, 28, 29, 30

  Plots in red were later thrown out of the study due to inaccurate treatments or erosion. If the 1st season of data is not compromised (i.e. plot eroded away), it is still present in the database.
- Biomass—None.
- Density and cover-- For brome on all 20 pairs. None for other vegetation. Cover estimates for substrate.
- Shrub density and richness—None.
- CBI—on all 20 pairs
- Pictures—on all 20 pairs.

FALL 2007

1. Kolob Terrace Rd
    - Plots—1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12. Block 7 was later shown to be compromised due to inaccurate application and was removed from analysis.
    - Biomass, density and cover—All 12 blocks and subsamples. Compromised subsamples later taken out of data.
    - Shrub density and richness-- All 12 blocks
    - Pictures—All 12 blocks. Typically 4 pictures per plot.
    - Soil for nutrient analysis—10-20 cores were deposited into one sample and analyzed for available P & pH
2. Dalton Wash
    - Biomass, density and cover—All 30 pairs and all subsamples.
    - Pictures—1 per plot taken from the west
    - Soil for nutrient analysis—5-7 cores were deposited into one sample and analyzed for available P & pH
3. Crater Hill

   **** Sampled 24 of the 30 pairs.
    - Plots-- 1, 3, 5, 6, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 26, 27, 30. Plots in red are not in the database. Threw out pairs 9 and 10 in future seasons due to incorrect pairing scheme. I hadn't been to the pairs at implementation or in previous seasons.
    - Biomass, density and cover-- All species and subsamples at all 24 pairs. Later threw out compromised subsamples.
    - Shrub density and richness—all 24 pairs
    - Pictures—all 24 pairs. Multiple pictures per plot.

SPRING & FALL 2008 AND SPRING 2009

4. Kolob Terrace Rd
    - Plots—1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12. Block 7 was later shown to be compromised due to inaccurate application and was removed from analysis.
    - Biomass, density and cover—All 12 blocks and uncompromised subsamples.
    - Shrub density and richness-- All 12 blocks
    - Pictures—All 12 blocks. Typically 4 pictures per plot.

5. Dalton Wash
    - Biomass, density and cover—All 30 pairs and all subsamples.

- Pictures—1 per plot taken from the west

6. Crater Hill
   - Sampled 23 of 30 pairs.
   - Plots-- 1, 3, 5, 6, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 26, 27, 30. Plots in red are not in the database. Threw out pair 9 in future season due to incorrect pairing scheme
   - Biomass, density and cover-- All species and uncompromised subsamples at all 23 pairs.
   - Shrub density and richness—all 24 pairs
   - Pictures—all 24 pairs. Multiple pictures per plot.