



In cooperation with Zion National Park and BASF Corporation

Reducing Fine Fuel Loads, Controlling Invasive Annual Grasses, and Manipulating Vegetation Composition in Zion Canyon, Utah

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Contents

Abstract	1
Introduction.....	2
Methods.....	6
Study Area	6
Experimental Treatments.....	7
Vegetation Measurements	9
Statistical Analyses	10
Results and Discussion	10
Fine Fuel Response.....	12
Brome Grass Response.....	15
Plant Community Response.....	16
Conclusions	21
Fine Fuel.....	21
Brome Grass.....	21
Plant Community.....	22
Management Implications.....	22
Deliverables.....	23
References Cited.....	24
Appendix.....	26

Figures

Figure 1.	General view of the study site.	6
Figure 2.	Fire and herbicide treatments begin applied.	8
Figure 3.	Landscape view showing differences among treatment plots during the first post-treatment year11
Figure 4.	Fine fuel response to biomass removal and herbicide treatments.	13
Figure 5.	Density response of brome grass to biomass removal, herbicide, and seeding treatments.	16
Figure 6.	Density response of the plant community to biomass removal, herbicide, and seeding treatments.	18
Figure 7.	Cover response of the plant community to biomass removal, herbicide, and seeding treatments19
Figure 8.	Species richness response of the plant community to biomass removal, herbicide, and seeding treatments.	20

Tables

Table 1.	Summary of weather patterns during the study.	26
Table 2.	Native seeds used and seeding rates used for revegetation plots in Zion Canyon.	26

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Abstract

Fine fuels created by non-native annual grasses are a land management problem throughout the United States and beyond. These fuels facilitate the ignition of wildfires and promote their spread, creating hazardous fuel conditions in wildland urban interface areas. For example, fine fuel accumulations from non-native annual grasses in the riparian corridor at Zion National Park threaten the few egress routes from Zion Canyon, creating a threat to human life should a large wildfire occur there. In addition, when these non-native plants create novel fuel characteristics and fire behavior, they can lead to altered fire regimes that can significantly degrade natural resources. Native riparian plant communities in Zion Canyon have already been degraded by non-native plants, and recurrent fire caused by annual grasses could further reduce native plant diversity.

There are very few success stories documenting effective control methods for fuelbeds created by non-native annual grasses. Among the methods that have been used with variable success rates are direct biomass removal, herbicide treatments, and seeding of less flammable species to compete with

and suppress productivity of the non-native annual grasses. In this study we compared biomass removal (burning or mowing applied in fall), herbicide application (imazapic applied at 12 ounces per acre in fall or spring), and seeding of other species (two native shrubs and three perennial grasses applied at 19.5 pounds per acre pure live seed in winter).

Results suggest that burning may have a more lasting effect than mowing in reducing fine fuel loads, at least extending the period between repeated maintenance a few years versus the current annual program of mowing in Zion Canyon. When burning is coupled with fall herbicide application, additional control of brome grasses might extend the maintenance interval even further due to the reduction in brome grass densities. The effects of seeding do not seem to be significantly manifested during the initial 3 years of this study, although the ultimate effects might not be obvious for a number of additional years.

Introduction

Hazardous fine fuels dominate Zion Canyon from the lower terraces along the Virgin River to the talus slopes descending from the base of the Navajo sandstone monoliths. The fine fuels are dominated by non-native invasive annual brome grasses—primarily cheatgrass (*Bromus tectorum*) and ripgut brome (*Bromus diandrus*). These non-native grasses senesce sooner in the growing season and produce a more continuous and flammable fuel bed than native annuals and perennials. They have the potential to dramatically alter fire regimes, creating an “invasive plant/fire regime cycle” (Brooks and others 2004) that helps perpetuate their dominance. Non-native annual plants have increased fine fuel loads and fuel bed continuity across the western United States, and they constitute one of the greatest hazardous fuel concerns in this region (D’Antonio and Vitousek 1992, Brooks and Pyke 2001).

The fuels and fire regimes of Zion Canyon are currently classified as Fire Regime Condition Class 3 (FRCC3, *sensu* Hardy and others 2001), which is to say that their condition is far outside of

their historically natural range of variation in key fuel and fire regime characteristics. This is in comparison to FRCC2, which represents a moderate departure, and FRCC1, which represents no departure, from historical conditions. This deviation is entirely due to the predominance of fine fuels from non-native annual plants in Zion Canyon. National park management is greatly concerned for the safety of the public, employees, and park partners in this area, which contains the highest level of infrastructure development and concentration of people in the park. With the conversion of a somewhat fire-resistant native riparian and river terrace community to a fire-prone non-native plant community, a fire start anywhere in Zion Canyon represents a great safety hazard because there is only one escape route from the narrow canyon. In addition to public safety, the multitude of park infrastructure and National Register historic properties prompted inclusion of the developed areas in Zion Canyon as a Wildland-Urban Interface treatment area to reduce fire hazards.

Personnel from Zion National Park have been mowing key areas annually to reduce fire hazards posed by non-native fine fuels, protect significant infrastructure, and maintain egress routes in Zion Canyon. However, annual mowing is not consistent with many National Park Service policies and can be very expensive. Other methods are needed to provide long-term control of non-native annual plants and to specifically convert the Fire Regime Condition Class from its current level of FRCC3 to its desired level of FRCC1.

Fine fuel loads can be reduced temporally through both prescribed fire and mowing. However, non-native invasive annuals are disturbance-adapted and recover from disturbances more quickly than do native species in arid to semi-arid regions of western North America (Brooks and Pyke 2001). Similarly, herbicides can reduce cover of fine fuels, but when applications are discontinued, annual weedy plants can readily disperse back into treatment areas. The only real hope for long-term management of fine fuels created by invasive non-native plants is to facilitate reestablishment of native

species, which will create a fuel-bed that better approximates historical conditions and thus promotes the restoration of the fire regime that existed before the non-native plants altered it.

This project addressed a significant research need that hinders the implementation of Zion's Fire Management Plan and other plans at land management units across western North America. It is important to identify effective tools for reducing fine fuels created by non-native annual plant species, restoring less flammable native perennial plant communities, and ultimately converting FRCC3 to FRCC2 or FRCC1 landscapes. This project established a demonstration study site so that the long-term effects of the treatments applied in this study can continue to be evaluated in the future well after the project is completed. This site will also serve as a living laboratory where scientists, managers, and policy makers can observe first-hand the effects of the treatments on the landscape.

Recent research studies and land manager experiences have indicated that the herbicide imazapic can effectively control annual brome grasses (Shinn and Thill 2002, Davidson and Smith 2007, Sheley and others 2007), which may provide a competitive advantage for existing and/or seeded perennial plants (Sheley and others 2007, Kyser and others 2007, Beran and others 1999, Shinn and Thill 2004). Application of imazapic prior to brome grass germination is generally recommended and, since imazapic is primarily absorbed from the soil by plant roots, should also preferably follow a reduction in standing vegetation biomass and litter to maximize herbicide contact with the soil (BASF Corporation 2006). Managers at Zion National Park have used imazapic for small-scale control of brome grasses in the past, but they felt that the efficacy of imazapic needed robust testing before it was applied at larger scales. Although pre-germination application is generally recommended, the mild, wet winters and coarse-textured soils in Zion Canyon may result in rapid movement of imazapic down through the soil profile and below the rooting zone prior to brome grass growth. Therefore, application of herbicide after

germination following winter rains may actually be more effective in this area, so the study was designed to determine the best application timing as well.

Zion National Park managers have primarily relied on mowing to manipulate fine fuel structure; however, mowing doesn't necessarily reduce fine fuel biomass, and the resulting thatch may impede herbicide contact with the soil. While prescribed fire may be the best option for biomass removal prior to herbicide application, it cannot be used in all situations—such as near existing park structures or when air quality restrictions limit burning—and it can be more costly and logistically difficult to implement as compared with mowing. This study compared the effectiveness of imazapic application following both mowing and prescribed fire.

Herbicides and other vegetation-control methods usually provide only short-term control of unwanted species, especially if there remains high propagule pressure from the invasive species and other competitive species are not immediately established. Zion National Park managers desire a plant community composed of native perennial grasses, forbs, and shrubs, which would also create a fuel bed with less horizontal continuity and reduced ability to carry wildfire. The dearth of native understory vegetation in Zion Canyon may limit the dispersal and successful reestablishment of plants into treated areas, so the final treatment component of the study included either seeding or not seeding plots with native species.

The specific objectives of this study were to: (1) Determine which combinations of biomass reduction, herbicide timing, and native plant seeding resulted in the greatest reduction in fine fuel loads; (2) Evaluate the effects of these treatment combinations on density and biomass of non-native brome grasses; and (3) Evaluate the effects of these treatment combinations on density and cover of other plant species, and on overall species richness of the plant community.

Methods

Study Area

The study site is located on the western edge of the Colorado Plateau in southwestern Utah. The site is located at 1,158 meter (3,800 foot) elevation on the North Fork of the Virgin River within Zion Canyon. The riparian area consists of old even-aged cottonwood trees (*Populus fremontii*) mixed with true willow species (*Salix* sp.) and seep willow (*Baccharis glutinosa* and *B. emoryi*). The upper river terraces contain scattered cottonwoods, velutina ash (*Fraxinus velutina*), and boxelder (*Acer negundo*). The understory is dominated by the non-native annual grasses cheatgrass (*Bromus tectorum*) and ripgut brome (*Bromus diandrus*) (fig. 1).



Figure 1. General view of the study site.

Mean annual precipitation in Zion Canyon is 36 to 43 centimeter (14 to 17 inches) and is distributed bimodally between summer monsoons occurring from mid-July to early September and winter frontal systems from November through March. Mean annual soil temperature is 49 to 56 °F (9 to 13 °C), and the frost-free period is 135 to 150 days. Yearly precipitation and temperature patterns during the study are summarized in Table 1 of the Appendix in this report.

Experimental Treatments

Experimental treatments were applied at four locations (experimental blocks) within Zion Canyon. Two blocks were within the riparian corridor immediately adjacent to the Virgin River and two blocks were located at the mouth of the canyon on upper riparian terraces. Each block contained 27 treatment plots, each measuring 15 × 15 meters with a 3-meter buffer between adjacent plots. The 27 treatment plots per block consisted of a factorial combination of two biomass reduction techniques implemented in the fall (burning or mowing), two timings of herbicide application (fall or spring), and two seeding treatments (seeded or non-seeded) with three replicates, plus three un-treated control plots. The untreated controls were not crossed fully with the three experimental factors, but rather were included to provide a comparison to completely untreated conditions (no active management treatments).

During fall 2005, existing fine fuel biomass within each treatment plot was reduced by either prescribed burning or mowing. Strip fires were ignited by hand-held drip torches and mowing was done by either a tractor-mounted flail mower or hand-held weed whackers. Dead and clipped biomass was left in place and not physically removed from the plots.

After biomass reduction treatments were applied, herbicide treatments with imazapic (Plateau®, BASF Corporation 2006) were applied either in fall prior to brome seed germination (October 2005) or in spring following brome seed germination (February 2006) (fig. 2). A backpack boom sprayer was

used to apply a spray volume of 20 gallons per acre, consisting of 12 ounces of imazapic per acre and one quart of methylated seed oil (a surfactant) in water per acre. Each treatment plot was also encircled with a 3-meter band of herbicide during the spring application to reduce brome grass seed rain from around each plot. Herbicide was only applied when the wind was less than 5 miles per hour and there was no dew on the ground.



Figure 2. Fire and herbicide treatments being applied.

Native seeds from common grass and shrub species were collected from Zion National Park over several years (2001 to 2004) for this project. All seeds were collected by hand from the main canyon area in order to maintain local genetic integrity. Seeds were cleaned and subsamples sent to the Los Lunas Plant Materials Laboratory, New Mexico to determine pure live seed percentages using germination tests appropriate for each species. The total seed application rate was 19.5 pounds per acre pure live seed and consisted of two shrub and three perennial grass species (Appendix—Table 2). The

species with larger seeds (*Atriplex canescens*, *Chrysothamnus nauseosus*, and *Elymus elymoides*) were seeded using a push-type drill seeder, and the other three species with smaller seeds (*Aristida purpurea*, *Sporobolus cryptandrus*, and *Sporobolus contractus*) were applied by hand broadcasting (seeding rates are given in the Appendix–Table 2). Seeds were sown in January 2006 and each seeded plot was raked lightly to cover the seeds with a small amount of soil. Non-seeded plots were also raked to avoid any confounding effects of raking.

Vegetation Measurements

Fine fuel biomass was measured within four 25 × 25 centimeter quadrats per treatment plot during late spring to evaluate treatment effects on the fuelbed at the beginning of the summer fire season and to capture brome grass productivity at its phenological peak. All above-ground fine fuel biomass was collected and sorted into four categories, which included live brome grass (*B. tectorum* and *B. diandrus*), live other herbaceous species, dead standing fine fuels, and litter. Coarse woody debris fuels rarely occurred and were not measured since they would have negligible effects on fuel loading and potential fire behavior. Live standing brome grass density was also measured within the same quadrats immediately prior to biomass collection during 3 years following the treatments (late spring 2006, 2007, 2008). Only fine fuel biomass and brome grass density data from the first two post-treatment years are included in this report, as the 2008 biomass data were not available when this report was written in fall 2008. Note that the original proposal for this project mentioned only that there would be 2 years of post-treatment sampling, and that the third year was done at not additional cost to the Joint Fire Science Program.

Plant species density was measured within four 1 × 1 meter quadrats per treatment plot during early fall to correspond with the period of peak productivity of the majority of the species at this study site. This includes the phenologic peak for the perennial species that were seeded. Cover for each

species was recorded using one 15 m point transect per treatment plot with points spaced every 0.3 m (50 points total per transect). Species richness was measured within individual 1, 10, and 100 m² circular subplots nested within each treatment plot. Cover, density, and species richness measurements were made in early fall to correspond to the period of peak productivity of the majority of the species at this study site. Measurements were made during 3 years following the treatments (early fall of 2006, 2007, and 2008).

Statistical Analyses

There were 324 total observations: 4 blocks \times 2 biomass manipulations \times 2 herbicide timings \times 2 seeding treatments \times 3 replicates \times 3 years, plus 36 additional observations from completely untreated controls (4 blocks \times 3 replicates \times 3 years). Most response variables were analyzed using mixed-effects models, which allowed specification of random effects (the four blocks) and repeated-measure effects (the 3 sampling years). A four-way factorial model (biomass manipulation, herbicide timing, seeding, and year) plus interactions was used. Control plots were not directly used in models, but graphically compared to the other treatment combinations. Model parameters, their standard errors, and statistical significance were calculated by maximum-likelihood estimation using functions contained within the Non-Linear Mixed Effects package (Pinheiro and others 2008) for the R statistical software system (R Development Core Team 2008). Response variables were transformed (usually by square root or logarithm) if needed to improve distributional normality of model residuals.

Results and Discussion

Visually, the plots displayed noticeable differences among treatment types during the first post-treatment year (fig. 3), and these differences were still somewhat evident during the ensuing 2 years. Empirical differences are reported in the sections below through post-treatment years 2 for fine fuels

and brome grass responses (final year 3 analyses were pending at the time this report was drafted in fall 2008) and through post-treatment year 3 for plant community responses. Because this report entered the USGS peer-review and approval process in fall 2008, we only present results for data that we were able to analyze up to that point in time. We will complete all analyses of data over 3 post-treatment years and submit final journal articles for publication during FY09.



Figure 3. Landscape view showing differences among treatment plots during the first post-treatment year.

Fine Fuel Response

Burning reduced total live and dead fine fuel loads by about 75%, and mowing reduced fine fuels by about 25%, compared to untreated controls during the post-treatment year 1 (fig. 4). Reduced fuel loads due to mowing were completely caused by reductions in live fuels, as dead fuels did not differ between mowed and control plots. In contrast, reduced fuels due to burning were due to reductions in both live and dead fuels. Live fuels were completely comprised of brome grasses in both treated and control plots during year 1. These live fuels were reduced to a greater degree in plots that had biomass reduction followed by fall herbicide (about 90% reduction) compared to spring herbicide (about 40% reduction) (fig. 4).

The effects of burning and mowing on total live and dead fine fuels were similar in both year 1 and 2, although the composition of these fuels differed (fig. 4). During year 2, live fuels included both brome grass and other herbaceous species that were mostly comprised of non-native *Brassica* spp. and other forbs and biennials. There appears to be a high degree of interannual variability in the relative species composition of live fine fuels in Zion canyon, and this variability is discussed in the paragraphs below. Dead fuel loads during year 2 remained similar in mowed and control plots, and greatly reduced in burned plots.

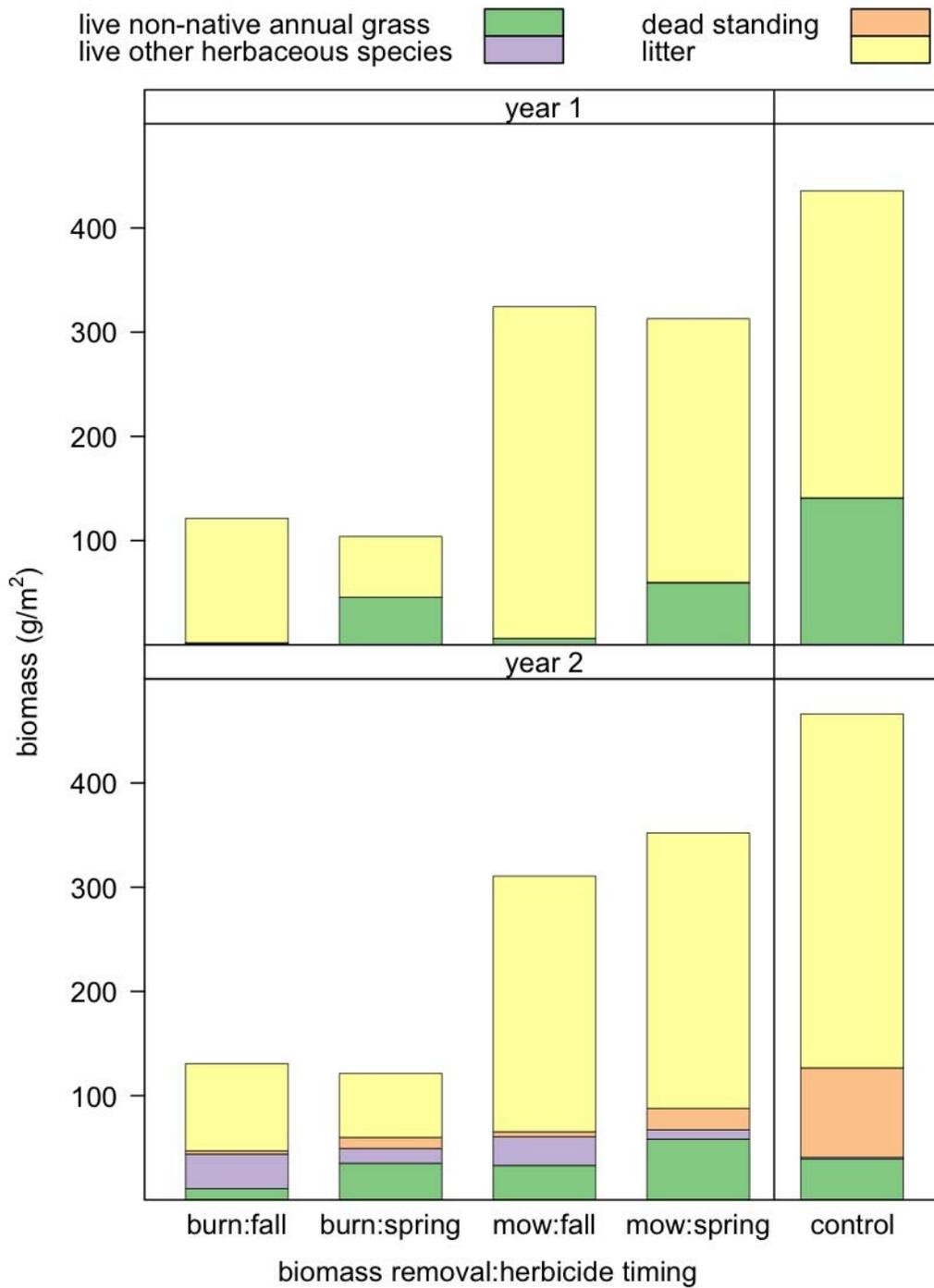


Figure 4. Fine fuel response to biomass removal and herbicide treatments.

If might be expected that mowing does not necessarily reduce dead fuels, but rather converts them from dead fuels to litter biomass. During year 1 all dead fine fuels were either flattened out in the control plots by previous snow, or converted to litter by mowing or partial burning, so there was no standing dead fuels detected. During year 2 there were standing dead fuels detected in all treatments, but they were greatly reduced in both mowing and burning plots compared to controls (fig. 4). This reduction was likely the result of reduced live brome grass biomass in treated compared to control plots during year 1, which carried over into year 2 immediately preceding the spring fine fuels sampling period as dead standing fuel, plus additional brome grass growth.

Although herbicide timing did not affect total live or dead fine fuel loads during either year, it did reduce the amount of live fine fuels during the first year, especially in response to fall herbicide application (fig. 4). During the first post treatment year the fall herbicide treatments were comprised almost exclusively of dead fuels, whereas the spring herbicide treatment included 20 to 50% live brome biomass. This pattern generally persisted into year 2, although live biomass of other herbaceous species increased in apparent compensation for brome grass reductions, especially in the fall herbicide treatments, such that total live biomass for all species was similar among the four biomass reduction and herbicide timing combinations. Reductions in live fuels can be viewed as reduced capacity for fine fuels to recover following treatments and, thus, a diminished re-treatment need to maintain reduced fuels levels.

Seeding treatments had no effect on fine fuel loads during the first 2 post-treatment years and were therefore not included in figure 4. Data for fuel loads during the third year of sampling are currently being compiled and will be included in the final manuscript that will be submitted for publication in a scientific journal.

Brome Grass Response

Since brome grasses are the primary fine fuel constituent of concern in Zion Canyon, the response of these species to the treatment combinations is of particular interest. We have already reported in figure 4 that brome grass biomass is reduced during year 1 in both mowed and burned plots, especially where fall herbicides compared to spring herbicides have been applied as a follow-up treatment, that only burning followed by fall herbicide results in reduced biomass levels into year 2, and that seeding treatments had no effect on brome grass biomass during the first 2 post-treatment years. We mentioned in the Introduction of this report that biomass removal is generally necessary to improve soil contact of imazapic and enhances its efficacy. It appeared that burning and mowing as a biomass removal techniques prior to herbicide application had similar effects on imazapic efficacy during year 1, but that only burned plots exhibited a carry-over effect enhancing imazapic efficacy into year 2. In addition to translating directly into fuel loads, these biomass results also provide insight into the effects of treatments on the reproductive potential of brome grasses, because biomass of annual plants is correlated with seed production (Crawley, 1997). Accordingly, the most effective treatments at reducing brome grass fuel loads and reproductive potential seems to be burning followed by fall herbicide application.

Another way of looking at brome grass response to treatments is to measure their densities, which are directly related to mortality rates and subsequent population trends. During year 1, burning reduced brome grass density by >99% when followed by fall herbicides, and by about 60% when followed by spring herbicides (fig. 5). This effect was likely the result of heat-induced mortality of seeds in the litter layer and at or below the surface of the mineral soil, which is a well-know effect of fire on annual plant species (DiTomaso and others 2006). In contrast, mowing reduced brome grass density by about 90% when followed by fall herbicides, but <1% when followed by spring herbicides.

By year 2 only the burned/fall herbicide plots still had reduced brome grass densities. The inference is that burning can reduce brome grass densities by about half, but that the effect only persisted into the second year where follow-up fall herbicide application further depleted the seedbank by killing newly germinated plants before they could reproduce.

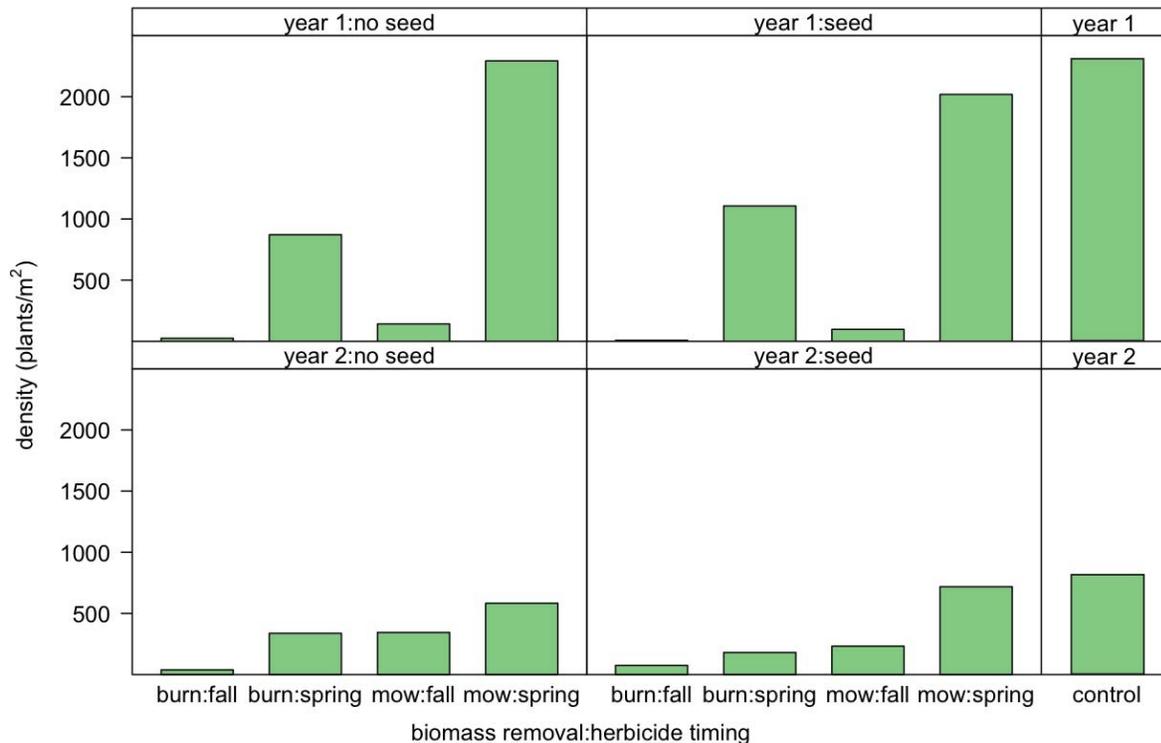


Figure 5. Density response of brome grass to biomass removal, herbicide, and seeding treatments.

Plant Community Response

During year 1, burning and mowing similarly decreased cover of native shrubs and perennial forbs, and increased cover of native perennial grasses and non-native annual forbs (fig. 6). Herbicides and seeding had no obvious effects on the vegetation. During year 2, the patterns were similar to the previous year, except that the decrease in native shrubs was less pronounced and the increase in native

perennial grass cover was more pronounced. By year 3, perennial grass cover was still higher in burned and mowed treatments, but non-native annual forbs were only higher in burned plots, especially those that had fall herbicides applied to them. In addition, there were no remaining effects on shrub cover and native perennial forbs. Thus, the effects that persisted into to the final year were increased perennial grass cover in response to both burning and mowing, and increased non-native annual forb cover in burned plots with fall herbicide application.

Responses of vegetation density were similar to, but more variable than, the responses of cover noted above. Native perennial shrubs densities were so low in the first place that their responses were negligible, and native perennial forb density was essentially unaffected by treatments (fig. 7). In contrast, density of non-native annual forbs, and especially native perennial grasses, increased dramatically during year 1 and 2, but were similar to controls by year 3. Density of perennial grasses was particularly enhanced in the seeded treatment plots during the first 2 years. All density responses were therefore only exhibited during the first 2 years.

The response in species richness varied, with statistically significant or near significant ($0.05 < p < 0.10$) effects of herbicide timing, seeding, year, herbicide x seeding, biomass removal x year, herbicide x year, and biomass removal x herbicide x seeding x year. Seeding appeared to have the most influence, usually increasing by 0.5 – 1.5 species (14%) across the three spatial scales, although its influence was not consistent among the other treatment combinations (fig. 8).

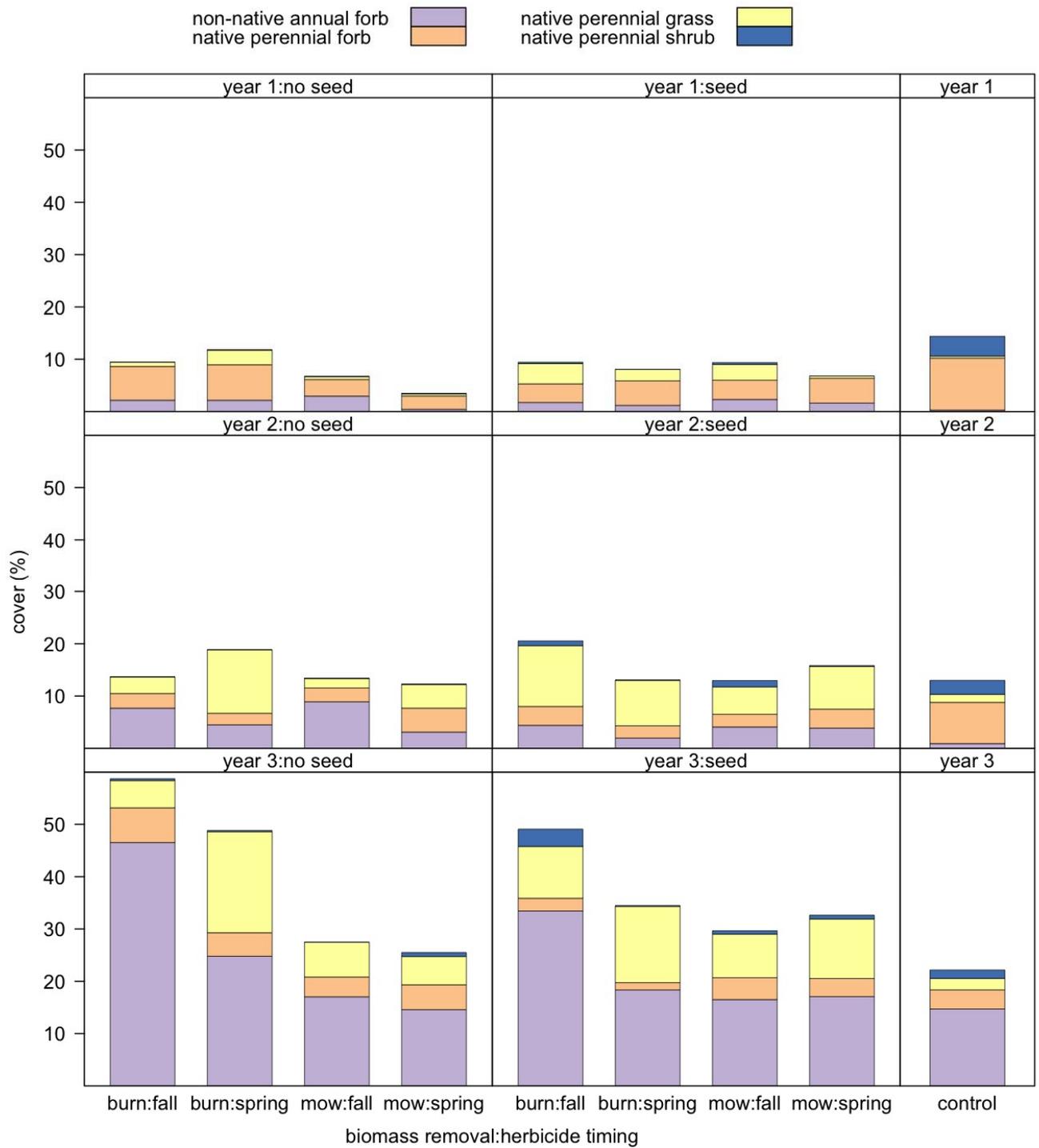


Figure 6. Density response of the plant community to biomass removal, herbicide, and seeding treatments.

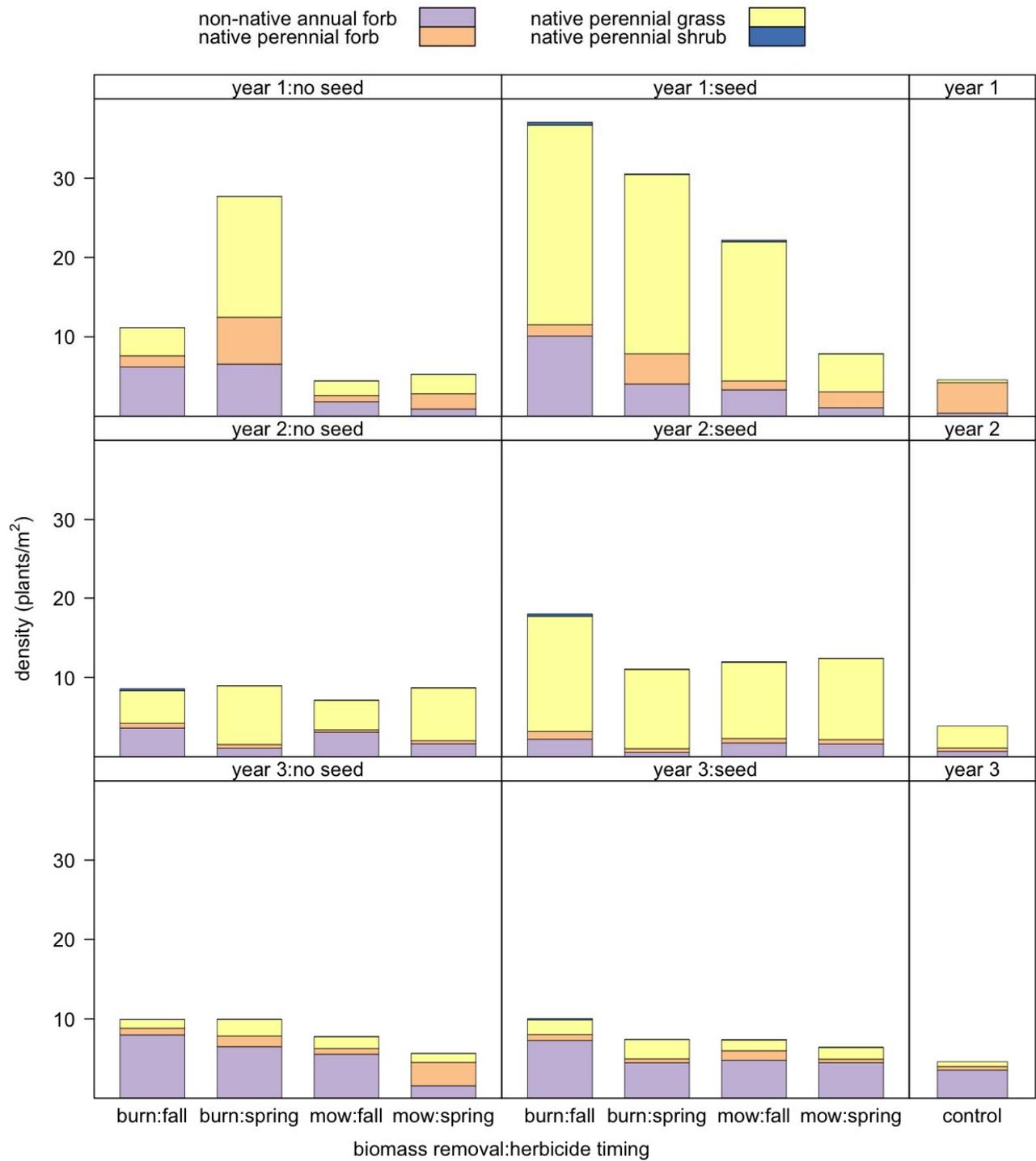


Figure 7. Cover response of the plant community density to biomass removal, herbicide, and seeding treatments.

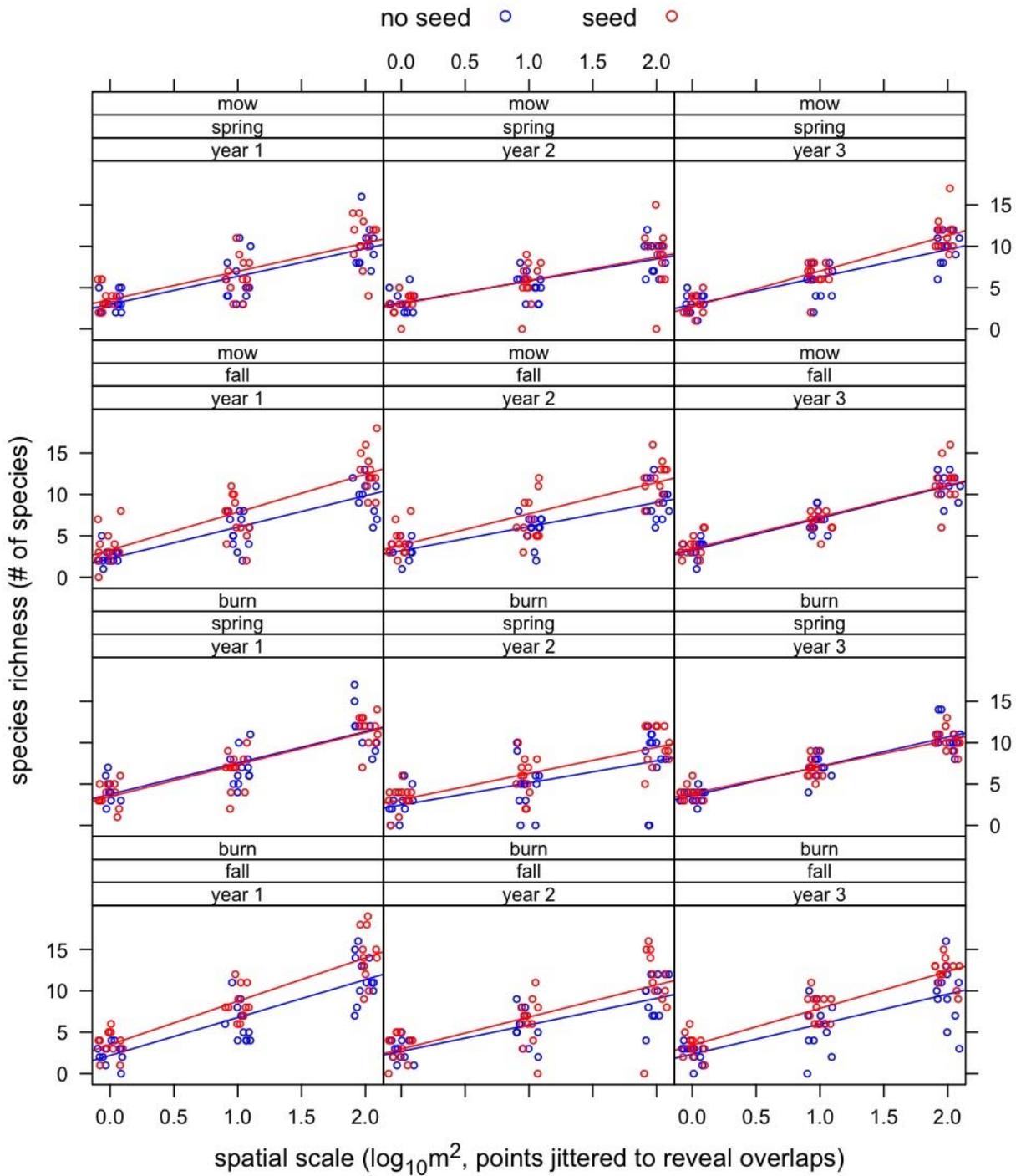


Figure 8. Species richness response of the plant community to biomass removal, herbicide, and seeding treatments.

Conclusions

Fine Fuel

- Fine fuel levels were reduced most effectively by burning which reduced fuel loads by more than twice that of mowing treatments during the first two post-treatment years.
- Burning had its greatest effects on dead fine fuels.
- In contrast, live fine fuels were reduced mostly by follow-up fall herbicide applications (especially following initial burn treatments) during year 1 when they were comprised completely of brome grasses. This initial reduction in brome grass carried over into year 2, but there appeared to be a compensatory increase in other herbaceous species such that live fuel loads were similar in treated and control plots that year. The key difference though is that the other herbaceous species were mostly forbs and biennials, which are not nearly as flammable as brome grasses. Reduced live fuel loads provides a longer-lasting effect of fuel reduction (by reducing reproductive rates) and a reduced retreatment need for retreatment.
- The greatest overall reduction in both dead fine fuels and live brome grass fuels was achieved by burning followed by fall herbicide application.

Brome Grass

- Burning during fall was more effective than mowing in reducing brome grasses biomass, and especially density, during the first two post-treatment years.
- Herbicide application during fall was more effective than spring application in reducing brome grass biomass and density during the first post-treatment year. This effect persisted into the second post-treatment year for burned areas but not for mowed areas.

- The best reduction in brome grass biomass and density was achieved by burning followed by fall herbicide application.

Plant Community

- Burning and mowing both reduced cover of native shrubs and perennial forbs, and increased cover of native perennial grasses and non-native annual forbs.
- Although there was some evidence of seedling establishment of native perennial grasses in seeded plots during the post-treatment year 1, this effect was not detected during the second and third post-treatment years, probably due to seedling mortality between the first and second years.
- Seeding increased species richness levels more than did biomass removal or herbicide treatment.

Management Implications

It appears that burning may have a more lasting effect than mowing in reducing fine fuel loads, at least extending the period between repeated maintenance a few years versus the current annual program of mowing in Zion Canyon. When burning is coupled with fall herbicide application, additional control of brome grasses might extend the maintenance interval even further due to the reduction in brome grass densities. The effects of seeding do not seem to be significantly manifested during the initial few years, although the ultimate effects might not be obvious for a number of additional years. Cursory monitoring of the study plots can be done annually to track any latent effects. If effects appear to be occurring (e.g., the presence of mature individuals of the seeded species coupled with reduced cover of brome grasses), then the sampling protocol used in this study may be re-implemented to document these changes.

Deliverables

Deliverable Listed in the Proposal	Delivery Dates
Year 1 progress report for the JFSP	Delivered Summer 2006
Integrate results into NAFRI FIEM course	Updated annually beginning in 2006
Year 2 progress report for the JFSP	Delivered Summer 2007
Field workshop at the demonstration site	Delivered Summer 2008
Final report for the Joint Fire Science Program	Delivered Winter 2009
Fact sheets and other interpretive information	In progress, scheduled for 30 Sept, 2009
Project website*	In progress, scheduled for 30 Sept, 2009
Peer-reviewed journal articles and publication briefs	In progress, scheduled to submit 30 Sept, 2009
Additional Deliverables	
A third year of post-treatment sampling beyond the 2 years that were listed in the original proposal. Some of these additional data were not available at the time this report was drafted in Fall 2008, but have been included in the journal article that we are currently developing.	
Periodic informal consultations with NSP staff regarding the management of brome grasses in the western United States	
12 presentations at symposia and workshops between 2006 and 2008	
Creative Component Report for Master's Degree at Ohio University (Aviva O'Neill)	
* The website material has been developed, but we are currently waiting for our USGS webmaster to complete a new standardized webpage template. We are told this will be completed and available summer 2009, so we expect the website to be available to the public by the end of FY09.	

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Appendix

Table 1. Summary of weather patterns during the study.

	Record or Average	2006	2007	2008
Total Precipitation	Average: 15.42 Max: (2005) 31.65 Min: (2002) 4.84	14.10	12.29	11.91
Wet Months of Year (Oct-Sep)		Oct (05), Mar, Apr, Jul	Oct (06), Apr, Aug, Sep	Dec (07), Jan, Feb
Dry Months of Year (Oct-Sep)		Nov(05), Dec(05), Feb, May, Aug	Nov(06), Jan, Mar, May, Jun	Oct (07), Nov(07), Mar, Apr, Aug, Sept
Wettest Day and Amount (in.)	(3/3/1938) 2.77	7/31 1.65	9/22 1.03	12/1/07 1.49
Days with measurable precipitation	61.9	70	72	57
Days with Precipitation > 0.50 in.	9	7	7	6
Winter/Spring Precipitation (in.) Oct-Apr	Average: 10.21 Max: (2005) 28.04 Min: (1977) 2.97	9.40	6.56	7.27
Monsoon Precipitation (in.) Jul-Sep	Average: 3.50 Max: (1984) 8.44 Min: (1945) .85	4.60	5.71	1.84
Number of days with snow	4	6	5	2
Annual Mean Temperature (Celsius)	Average: 61.1	62.7	63.6	62.6
Warm Months *Exceptionally Warm		May, Jun, Jul	*Mar, *May, Jun, Jul, Aug	*Nov, Jul, Aug, Sep
Cool Months		Mar, Sep	Oct, Jan	Dec, Jan
Number of days 100 °F and over	Average: 37.2 Max: (2007) 68 Min: (1983) 10	49	68	57
Number of Days 32 °F and below	Average: 73.5 Max: (1949) 124 Min: (1934) 47	78	82	73
Number of days 20 °F and below	Average: 13.1 Max: (1949) 39 Min: (1945) 0	6	16	12

Table 2. Native seeds used and seeding rates used for revegetation plots in Zion Canyon.

Common Name	Scientific Name	Pounds Per Acre Pure Live Seed
Purple threeawn	<i>Aristida purpurea</i> Nutt.	3
Four-wing saltbush	<i>Atriplex canescens</i> (Pursh) Nutt.	3
Rubber rabbitbrush	<i>Chrysothamnus nauseosus</i> (Pallas) Britt.	4
Squirreltail	<i>Elymus elymoides</i> (Raf.) Swezey	5
Spike dropseed combined with Sand dropseed	<i>Sporobolus contractus</i> A.S. Hitchc and <i>Sporobolus cryptandrus</i> (Torr.) Gray	4.5