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Executive Summary

The restoration of historical fuel conditions and fire regimes is one of the primary land management goals in the Shivwits Plateau region of northwestern Arizona. Fire is the primary tool used in this region to reduce fuel loads and shift landscapes back to historical conditions of a low intensity, 8-15 year return interval, surface fire regime. However, the invasive plant cheatgrass has become the dominant understory vegetation and fuel type following initial fire treatments in many areas. There is significant concern that repeated burning at historically appropriate fire return intervals for ponderosa pine forest will benefit this invasive plant to the detriment of native species. There is additional concern that the high flammability of cheatgrass fuelbeds will lead to fire return intervals that are more frequent than occurred historically and that are prescribed in the agency fire management plans, potentially preventing recruitment of pine seedlings and leading to type conversion of native forests to alien grasslands.

Federal land managers and research scientists have noted that cheatgrass does not typically co-occur with two of the dominant perennial grasses in the Shivwits plateau region, bottlebrush squirreltail (*Elymus elymoides*) and blue grama (*Bouteloua gracilis*). This suggests that these natives may be competing with and excluding the establishment of cheatgrass. If these species can be established in postfire landscapes, they may be able to pre-empt the establishment of cheatgrass and promote the restoration of native plant communities and natural fuel characteristics. This report provides results of an experimental seedings of these two perennial grasses.

Seeding with or without raking had no detectable effects on any of the species or groups of species in this study as measured by: 1) the density, cover, and species diversity of standing vegetation during the first 5 post-treatment years; or 2) the density and species diversity of the soil seedbank during the first 3 post-treatment years. Blue grama had an overall low standing density and cover, and seedbank density, at the study site, whereas bottlebrush squirreltail had relatively high standing density and cover, and seedbank density, at least during some of the sampling years. Cheatgrass did not differ among treatments, including raked and unraked plots, and only increased from 1.1 seeds per 18 cubic cm of soil immediately following the fire in fall 2003 to 1.5 seeds by the fall of the third postfire year.

These results suggest that blue grama may be an inappropriate species for seeding at this study site, whereas bottlebrush squirreltail may be an appropriate species. Although the natural recovery of the latter species within a few years following fire suggest that seeding may not be necessary. In addition, cheatgrass may not be a significant postfire management concern at this study site. Additional research is needed to more definitively evaluate the effects of seeding treatments, document the postfire recovery rates of cheatgrass and other species under a wider range of environmental conditions, and determine if there is a specific fire prescription that can both control cheatgrass and accomplish other fire management objectives.

Introduction

The ponderosa pine forests of western North America evolved with a frequent, low to moderate-intensity surface fire regime, fueled by light surface fuels that accumulated during the 5-15 year interval between fires (Covington and Moore 1984). As Anglo-American settlers populated the west during the late 1800s and into the 1900s, they imparted influence on the landscape that included fine fuel removal through livestock grazing and fire suppression to protect valuable resources such as timber stands. Reduced fine fuel loads and fire suppression led to greatly extended fire return intervals. As a result, understory fuels in ponderosa pine forests accumulated to higher levels, became woodier, and reached higher up into the forest canopy than they did prior to settlement. These historically unprecedented fuel conditions produced a new fire regime of infrequent, high intensity and severity, crown fires and generally reduced plant species diversity. Changes in fuel structure, fire regime, and vegetation composition such as this are characterized as shifts in fire regime condition class (FRCC) from historical, pre-settlement, or otherwise "natural" conditions (FRCC 1), to moderate (FRCC 2), and high (FRCC 3) departures from historical conditions (Hann and Bunnell 2001). Many of the ponderosa pine forest stands in western North America are currently classified as FRCC 2 and 3, and fire management plans include various treatments designed to return them to FRCC 1 conditions. Among the various treatment options, prescribed fire is the most common.

Plant invasions are considered to be one of the greatest threats to ecosystem integrity and conservation worldwide, especially invasions that alter fuels structure and fire regimes (Vitousek 1900, D'Antonio and Vitousek 1992, Brooks et al. 2004). Conifer forests are generally less vulnerable to plant invasions than are shrubland or grassland ecosystems (Pierson and Mack 1990a,b). This lesser vulnerability to invasion is thought to be due to high levels of shading from the forest canopy and native understory vegetation. Disturbances such as scraping, logging, herbicide treating, or burning significantly reduce canopy shading and often lead to increased dominance of the invasive alien grass cheatgrass (*Bromus tectorum*) in ponderosa pine ecosystems (Pierson and Mack 1990b, McDonald and Everest 1996, Crawford et al. 2001). These observations have raised significant concerns among land managers because this species is known to alter fuel and fire regimes in shrubland ecosystems, significantly reducing fire return intervals to the point that native shrubland species cannot regenerate, and type converting shrublands to invasive alien grasslands (Whisenant 1990, Brooks and Pyke 2001).

The concern regarding the long-term effects of management burns on cheatgrass and ponderosa fire regimes prompted managers at Kings Canyon National Park to halt their ponderosa management burns until they determined if they were doing more harm than good. Increased dominance of cheatgrass in that area was coincident with the initiation of management burns in the 1980s (McGinnis and Keeley 2007). Information from the Joint Fire Sciences Project "fire and invasive alien annual grasses in western ecosystems" (#00-1-2-04) (www.firesceince.gov) has indicated that there may be a narrowly defined burn prescription that could minimize the positive effects of fire on cheatgrass. However, results from that project also indicate that additional postfire management may be needed to affect long-term management of cheatgrass and to assist in landscape conversion back to historical native vegetation, fuel, and fire regime conditions. Fire is a critical tool in accomplishing this, but so too is control of cheatgrass and the restoration of native vegetation.

Research on the management of cheatgrass in forested ecosystems is just beginning to be addressed. As a result, there are many significant management questions that remain unanswered, such as the effectiveness of native seedings in suppressing cheatgrass. There is some evidence that seeding of native perennial grasses may help minimize cheatgrass dominance and maximize native plant cover and diversity after prescribed fire in forested ecosystems. For example, in areas where chaining to remove closed canopies of pinyon and juniper trees was followed by seeding of native perennial grasses a few decades ago, relatively high diversity sagebrush steppe with very little cheatgrass occurs today (M. Brooks pers. obs.). Also, where native perennial grasses such as the cool season grass bottlebrush squirreltail and the warm season grass blue grama occur naturally after fire in ponderosa pine forest, cheatgrass dominance is low and diversity and cover of native perennial grasses, shrubs, and forbs is high (M. Brooks and Curt Deuser, pers. obs.). Peak growth rates of native perennial grass species during both the cool and warm seasons may provide a wide temporal range of competitive exclusion of cheatgrass. These native perennial grasses were undoubtedly more abundant historically prior to fire suppression and the development of a dense woody understory. The loss of these grasses from many areas may be one of the reasons cheatgrass is so successful. Thus, seeding of bottlebrush squirreltail and blue grama may be an effective tool to re-establish these species and suppress cheatgrass following fire treatments.

Seeding treatments often exhibit poor establishment rates if the seeds are not somehow integrated into the soil (Lynch 2003). Fewer seeded species means lesser competitive effects on cheatgrass growth and reproduction. On the other hand, mechanical soil disturbance associated with seedbed preparation (e.g. chaining, disking, or raking) can improve site conditions for cheatgrass and other alien grasses (Lynch 2003, Scoles et al. 2003, M. Brooks et al. unpublished data). Soil disturbance can also damage cultural resources, which complicates seedbed preparation in areas with abundant cultural resources that need to be left undisturbed. Studies are therefore needed to determine if mechanical seedbed preparation such as raking significantly improves the establishment rates of seeded species, promotes the cover and diversity of natives, and ultimately reduces the dominance of aliens. This information will help determine if seedbed preparation should be a component of postfire seeding treatments.

Objectives and Hypotheses

1. Determine if raking after seeding improves establishment rates of bottlebrush squirreltail (*Elymus elymoides*) and blue grama (*Bouteloua gracilis*).
   Hypothesis: Bottlebrush squirreltail and blue grama density, cover, and seedbank density will be higher in plots that were raked immediately after seeding than in plots that were not raked.

2. Determine if raking after seeding affects the productivity of cheatgrass and other alien plants.
   Hypothesis: Cheatgrass and other alien plant density, cover, and seedbank density will be different in raked than in unraked seeded plots.

3. Determine if postfire seeding of bottlebrush squirreltail and blue grama decreases the productivity of cheatgrass and other alien plants.
   Hypothesis: Cheatgrass and other alien plant density, cover, and seedbank density will be lower in seeded than unseeded plots.

4. Determine if postfire seeding of bottlebrush squirreltail and blue grama increases productivity and diversity of native plants.

Hypothesis: Native species standing density, cover, and diversity, and seedbank density and diversity, will be higher in seeded than unseeded plots.

5. Develop recommendations regarding the use of postfire seeding and raking to reduce growth and reproduction of cheatgrass in recently burned ponderosa pine forest.

6. Establish a demonstration site and interpretive materials to illustrate the relative effects of postfire seeding, seeding plus raking, and no seeding on cheatgrass dominance and native plant productivity and diversity.

Methods

Study Area

The study site was within a locale known as Pine Valley Meadow on the western edge of the Colorado Plateau, within the Grand Canyon –Parashant National Monument, an area jointly managed by the Monument staff, the Lake Mead National Recreation Area, and the Bureau of Land Management, Arizona Strip Field Office (Figure 1). The site was at 7,000 feet (2,134 m), on flat terrain and dominated by ponderosa pine (*Pinus ponderosa*), basin big sagebrush (*Artemisia tridentata*, spp. *tridentata*), and rabbitbrush (*Chrysothamnus naseousus*) with a high frequency of cheatgrass in most areas. Mean annual precipitation was 13 to 17 inches (33 to 43 cm), bimodally distributed in summer monsoons from late June to early September, and winter frontal systems from November through March. Rainfall was highly variable during the study period, 2003-2008 (Figure 2). Mean annual soil temperature was 49 to 56 degrees F (9 to 13 degrees C), and the frost-free period was 135 to 150 days.

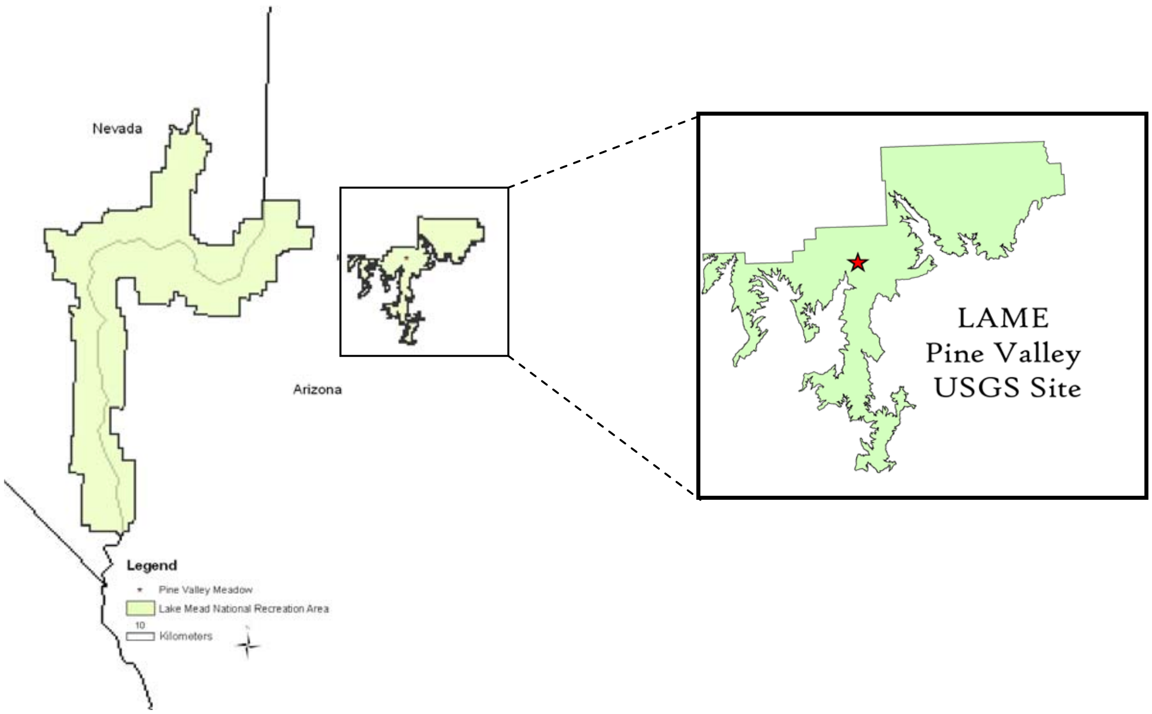

Figure 1. Location of the Pine Valley Meadow study site within the Grand Canyon – Parashant region of the Lake Mead National Recreation Area (LAME).

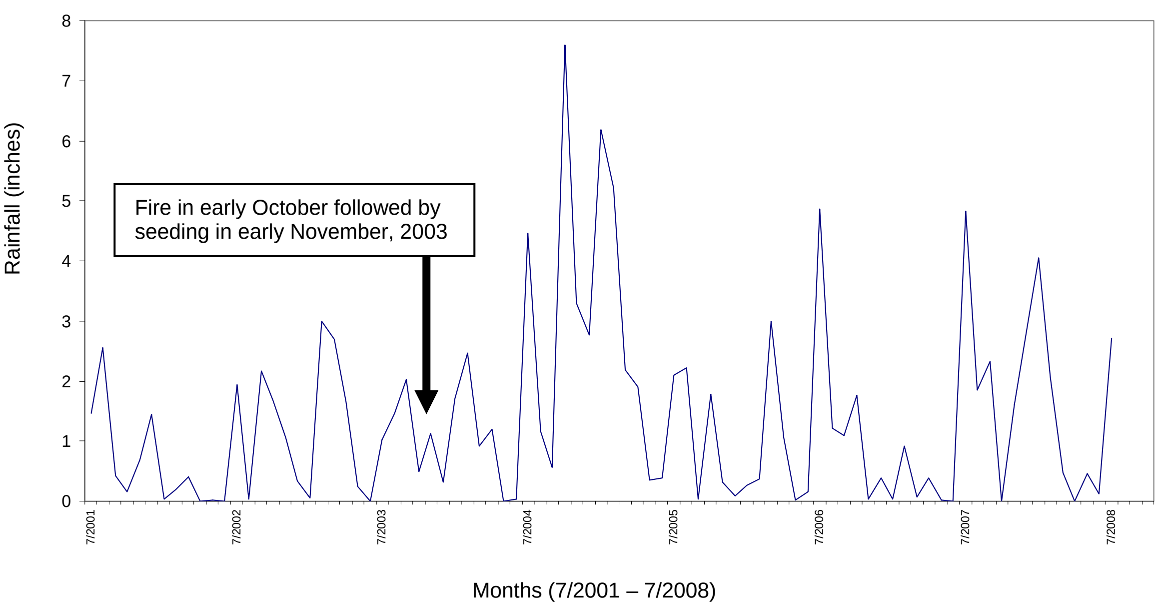

Figure 2. Monthly rainfall (in) at the Yellow John RAWS station, 4 miles from the study site (http://www.raws.dri.edu/cgi-bin/rawMAIN.pl?azAYEL). The hydrologic year was defined as July (beginning of the monsoon) through June. Data are presented for the two hydrologic years prior to the seeding treatments (7/2001 – 6/2003) and the 5 hydrologic years during the course of the study (7/2003 – 6/2008).

Study Design and Experimental Treatments

A meadow opening in the ponderosa pine forest was chosen for the study area rather than a location beneath the forest canopy for two main reasons. First, growth of understory vegetation can be impeded by shading from the canopy and needle cast and duff accumulations on the forest floor, especially during the initial stages of seedling establishment (Facelli and Picket 1991, Naumburg and DeWald 1999). Although much of the material on the forest floor is removed by fire, significant needle cast can be stimulated by fire and occur during the first few postfire years. The plan was to first see how easily perennial grasses might establish under the best-case scenario of on open meadow. If they cannot establish there, then there may be no point in trying to experimentally evaluate their establishment from seed under the forest canopy. Second, the environment under the forest canopy is also less conducive to cheatgrass growth for the same reasons as it may impede establishment of seeded perennial grasses, and we wanted to ensure that there was ample cheatgrass to study during the first few postfire years.

The study area was burned during the week of 6 October, 2003, as part of an ongoing program to reintroduce fire to ponderosa pine forests on the Shivwits Plateau. Concern that cheatgrass may dominate the site and promote recurrent fire after burning, and questions as to which seeding treatments would be most effective at minimizing cheatgrass dominance, prompted the federal land managers to ask USGS scientists to develop an experimental design testing the effectiveness of contrasting seeding treatment methods. The experiment began with the implementation of the two seeding treatments during the week of 3 November, 2003, one month after the management burn. The seed mix included the cool season grass bottlebrush squirreltail at 3 lbs/acre pure live seed, and the warm season grass blue grama at 2 lbs/acre pure live seed. Seeds for both species were Colorado Plateau ecotypes purchased from the Granite Seed Company in Utah. A backpack “whirlybird” applicator was used to apply the seed (Figure 3). Shallow furrows ~1 inch (2.5cm) deep were created using single strokes of a metal rake in the raked treatment plots. Approximately 1 inch of rainfall occurred within 2 weeks of seeding, and seemed to create ideal conditions for seed germinations, thus increasing the potential to evaluate their effects on cheatgrass growth and reproduction during subsequent years.

Seeding, seeding plus raking, and unseeded controls were each randomly applied to 6 replicate treatment plots (n=18 total treatment plots). Treatment plots were each 25 x 50m (1,250m^2). The 18 treatment plots were randomly located within 7 of the least erosional areas of the meadow to avoid major gullies. This was done to minimize the potential for losing plots during the course of the study through flooding. Six of these areas each contained 2 treatment plots and the seventh and largest contained 6 treatment plots. The sizes and shapes of these 7 areas did not permit complete replication of all three experimental treatments within each of them. However, their differing positions within the meadow warranted treating them as experimental blocks, resulting in an incomplete blocks design.

Figure 3. Seed being applied to burned areas using backpack applicators during the week of 3 November, 2003.

Sampling Methods for Response Variables

The sampling plot consisted of a 5 x 30m FMH brush belt transect (USDI National Park Service 2001). The edge of each sampling plot was >2.5m from the other and from the treatment plot edge. Prior to seeding during fall 2003, a single sampling plot was installed and measured within each treatment plot to document any residual plant density and cover that may have escaped burning, and to evaluate the baseline condition of the soil seedbank. These same plots were sampled during summer 2004 for vegetation and fall 2004 for seedbanks to document conditions during the first post-treatment year. A second sampling plot was added within each treatment plot in summer 2005 supported by funding from the Joint Fire Science Program. Thus, two sampling plots were sampled within each treatment unit during summer and fall 2005 – 2008 (Table 1).

Table 1. Sampling timeline for above-ground plants (density, cover, and richness) and soil seedbanks.

	Immediate Pre-seeding	Post-seeding Years				
		1	2	3	4	5
	2003	2004	2005	2006	2007	2008
Rx fire	Oct					

Vegetation						
Density	Nov	summer	*summer*	*summer*	*summer*	summer
Cover	Nov	summer	*summer*	*summer*	*summer*	summer
Richness	Nov	summer	*summer*	*summer*	*summer*	summer
Soil Seedbank						
Density	Nov	fall	*fall*	*fall*	fall	none
Richness	Nov	fall	*fall*	*fall*	fall	none
Photos						
	Nov	summer	*summer*	*summer*	*summer*	summer

Sampling supported by this JFSP contract 05-2-1-17 underlined and in italics

Density of woody perennial plants (trees and shrubs) was measured within the 5x30m belt transect. Each individual having >50% of its rooted base within the belt transect were counted. Data were recorded by species and age class. Age class of each individual was identified as either dead, immature-seedling, resprout, or mature-adult (USDI National Park Service 2001). Cover and height of woody perennial plants and bare mineral soil were measured by line intercept, using the two 30m sides of the brush belt transect as subsamples. Data were recorded by species and age class (USDI National Park Service 2001).

Cover of herbaceous plants was measured by the point-intercept method, using the two 30m sides of of the brush belt transect as subsamples. Starting at the end of each transect and repeated every 30 cm, a 0.25inch diameter sampling rod (a rigid plumb bob) graduated in decimeters were lowered gently so that the sampling rod was plumb to the ground. Since the transect length was 30 m, there were 100 points from 30 to 3,000 cm. The height at which each species touched the sampling rod was recorded, tallest to shortest. If the rod failed to intercept any vegetation, the substrate was recorded (bare soil, rock, forest litter, etc.) (USDI National Park Service 2001). Density of herbaceous plants was collected within six 1m^2 (100 x 100cm) subplots placed at 5m intervals along each of the two 30m sides of the brush belt transect as subsamples. Herbaceous plants were counted by species for each frame, separating live and dead individuals (USDI National Park Service 2001).

Species diversity was measured as the number of species (species richness) at two spatial scales, within the 1m^2 herbaceous density subplots and within the 150m^2 belt transect (sampling plot). The effects of land management actions on plant diversity can vary among spatial scales (Stohlgren et al. 1999, Brooks and Matchett 2003), so sampling at contrasting scales is often necessary to effectively evaluate response variables.

Seedbank density and species composition were measured from composited soil samples each comprised of 4 pooled sub-samples collected near the corner of each brush belt transect. All soils were collected using a 6cm diameter x 3cm deep core. Soil seedbanks were assayed by growing them out in a greenhouse and counting the number of seedlings for each species. The methods were adapted from Brenchley and Warington (1939), later modified by Young and Evans (1975).

Photomonitoring plots were installed in each treatment plot following the NPS-FMH protocols (USDI National Park Service 2001). These plots provide important visual documentation that were used in the development of interpretive information for the demonstration site, and will provide a baseline for long-term photomonitoring that will be continued by the Lake Mead National Recreation Area to evalute the long-term effects of seeding treatments past the end of the proposed project.

Statistical Analyses

Hierarchical models (Gelman and Hill 2007) were used to analyze differences in stem density, cover, and species richness of standing vegetation. Species categories included non-native annual grasses and forbs, native annual forbs, native perennial forbs, native annual and perennial grasses, and native shrubs. Non-native grasses and forbs were pooled into a single group because of low abundance and restricted distribution of each of these individual guilds. Similarly, native annual and perennial grasses were pooled into a single group because of low abundance and restricted distribution of native annual grasses. Repeated measures analysis of variance (rmANOVA) could not be used because of the incomplete block design. In contrast, hierarchical models are a very flexible and robust set of methods based on maximum-likelihood estimates of parameters, rather than ordinary least square estimates used in rmANOVA. Because they are based on maximum likelihood estimates, they can handle situations such as at Pine Valley Meadow where additional plots were added during the course of the project and not all treatments occurred in each block. The models were based on a Gaussian error structure and identity link function (Gelman and Hill 2007). The analyses used variance proportion hierarchical modeling with block as a random factor. Fixed factors in the models included treatment, year, and the treatment-by-year interaction. All dependent variables were $\log_{10}+1$ transformed so that residuals met the assumption of having an approximately normal distribution. Based on inspection of normal probability and residual plots, there were no serious departures of the residuals from normality for any of the analyses.

Hierarchical models were also used to analyze the density of bottlebrush squirreltail and cheatgrass seedlings that emerged in the soil seed bank assays. Density of blue grama seedlings was not analyzed because none occurred in the samples (see Results). Fixed-effect variables in the analysis included year (200-2008) and year^2, seeding, raking, and all two and three-way interactions among those variables. Random factors in the model included block and plot. The models were based on a Gaussian error structure and identity link function, with seedling density $\log_e+1$ transformed to meet the assumption of residuals having an approximately normal distribution. All of the variables were retained in the model, with significance ($P \leq 0.05$) determined by a z-test (Gelman and Hill 2007).

Distance-based redundancy analysis (DbRDA) was used to evaluate the relationships of native and non-native species to treatments and environmental variation. DbRDA is a canonical version of principal components analysis that uses a distance matrix and reciprocal averaging to evaluate the relative position of species, sampling plots, or both along axes constrained by environmental or treatment variables (Legendre and Anderson 1999). The method is particularly suited to the responses of multiple species from experimental treatments or along short environmental gradients (Legendre and Anderson 1999). Percent cover of each species was used to calculate a matrix of Bray-Curtis dissimilarities (Legendre and Legendre 1998), and non-metric multidimensional scaling (NMDS; Clarke 1993) to determine the number of dimensions from the distance matrix to include in the DbRDA (Leps and Smilauer 2003). Based on a Shephards plot and measures of stress, a three-dimensional solution from the NMDS was used as the input distance matrix for the DbRDA (Clarke 1993, Leps and Smilauer 2003). The environmental variables in the DbRDA included treatment (control, seeded, seeded and raked) and years. Significance of the analysis was based on 500 random permutations of the data for the first axis and the overall axis (Leps and Smilauer 2003).

Analysis of Similarity (ANOSIM) followed by a similarity percentage analysis (SIMPER) was used to evaluate differences in species composition of the soil seedbank among treatments (all combinations of seeding and raking) and year for the seedbank data. ANOSIM is a non-parametric multivariate analysis of variance that uses a distance matrix to determine if species composition differs between two or more conditions (Clarke 1993). A test statistic *R* is calculated that measures the mean rank dissimilarities between groups relative to within groups. *R* can range between 1 and -1; as *R* approaches 1 species composition is increasingly greater between groups than within groups, *R* values near 0 indicate no differences in species composition between groups, and *R* values that approach -1 indicate species composition is more different within groups than between them. The Bray-Curtis dissimilarity measure (Legendre and Legendre 1998) calculated from the relative number of shoots per plot and 999 bootstrap samples was used to determine the significance of *R*. SIMPER was conducted after an ANOSIM to compute the percentage contribution of each species to the dissimilarities. It uses the Bray-

Curtis coefficient to compute the percentage contribution of each species to the dissimilarity between all pairs of sampling plots between groups and within groups (Clarke and Warwick 1994). Species with a large average dissimilarity/standard deviation ratio are those that discriminate most between groups. Changes in species composition of the soil seedbank relative to the baseline year of 2003 were reported.

Results

Standing Vegetation

A total of 72 species were recorded in the plots (Appendix A – Table 2). Eleven species (15.3%) were non-native, including two grasses (*Bromus tectorum* and *B. inermis*) and nine forbs. Six native species were shrubs, nine were grasses, and the rest forbs.

Seeding and seeding plus raking treatments did not significantly differ from controls in terms of cover or density of the seeded species or any of the species guilds (Appendix B, Tables 4-6). Species diversity did not display differences among treatments either (Table 7). The Block factor had a significant effect on the response variables in 13 of the 15 ANOVA analyses (87%), and the sampling Year factor was significant in 100% of the analyses (Appendix B, Tables 4-7). These results suggest that standing vegetation differed significantly among locations within the meadow and among years of contrasting environmental conditions, however the proportion of variance attributed to Year was an order of magnitude higher than that attributed to Block (Appendix B, Tables 4-7).

Cover and stem density of blue grama did not vary significantly among years, however cover and density of bottlebrush squirreltail was much higher in 2006 than the other years (Figure 4). Cover of non-native herbaceous species (Figure 5) and cover and density of native annual forbs (Figures 6 and 7) was significantly greater in 2005 and 2006 than the other years. The high density of stems of native annual species in 2005 and 2006 was due primarily to one species, *Portulaca oleracea*. *Portulaca oleracea* was recorded only in 2005 and 2006, but mean stem density was 119 and 300 stems m^2 during those years, respectively. This comprised approximately 68% of the mean herbaceous stem density in 2005 and 25% in 2006. Cover and stem density of native grasses peaked in 2006 (Figures 6 and 7). Non-native herbaceous species comprised less than 8% of the total relative cover and less than 2% of the total stem density. Over 91% of the cover and 63% of the stem density of non-native herbaceous species was comprised of annual forbs.

Mean species richness was significantly greater in 2005 and 2006 than the other years (Figure 8). The N1 and N2 indices were both significantly lower in 2007 than the other years, while Pielou's index of evenness trended towards being greater in 2004 and 2008 than 2005-2007 (Figure 8).

The first two axes of the DbRDA explained 76% of the variation in species composition (Table 9). Both axes were clearly indicative of strong interannual variation; the first axis was a gradient between 2005 and 2008, while the second axis represented a gradient from 2004 to 2006 (Figure 9). Treatment condition had virtually no influence on vegetation species composition (Table 8 and Figure 9).

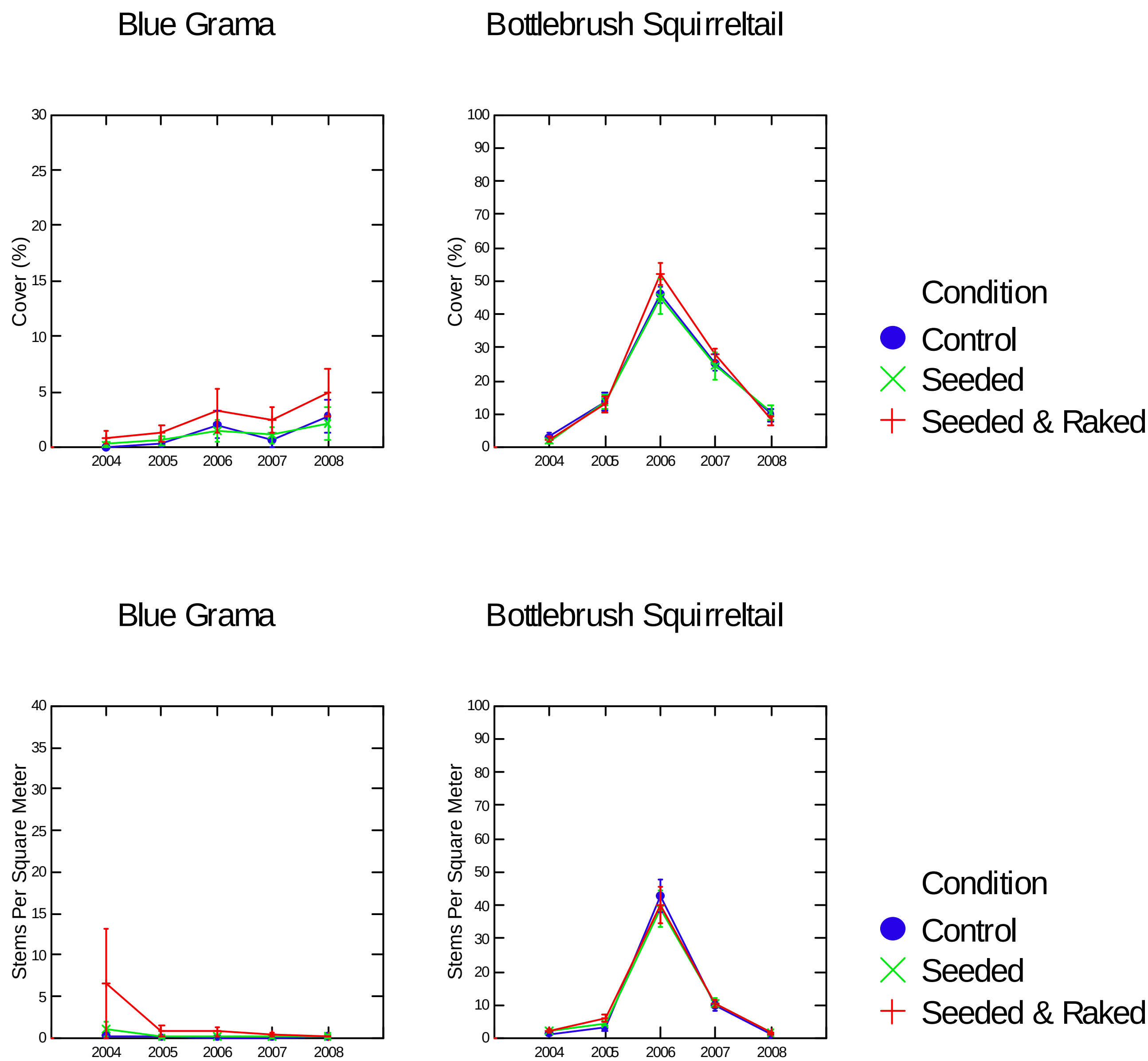

Figure 4. Mean cover and stem density (± SE) of two species of native grasses seeded into three postfire conditions in Pine Valley Meadow, Arizona. The species were blue grama (*Bouteloua gracilis*) and bottlebrush squirreltail (*Elymus elymoides*).

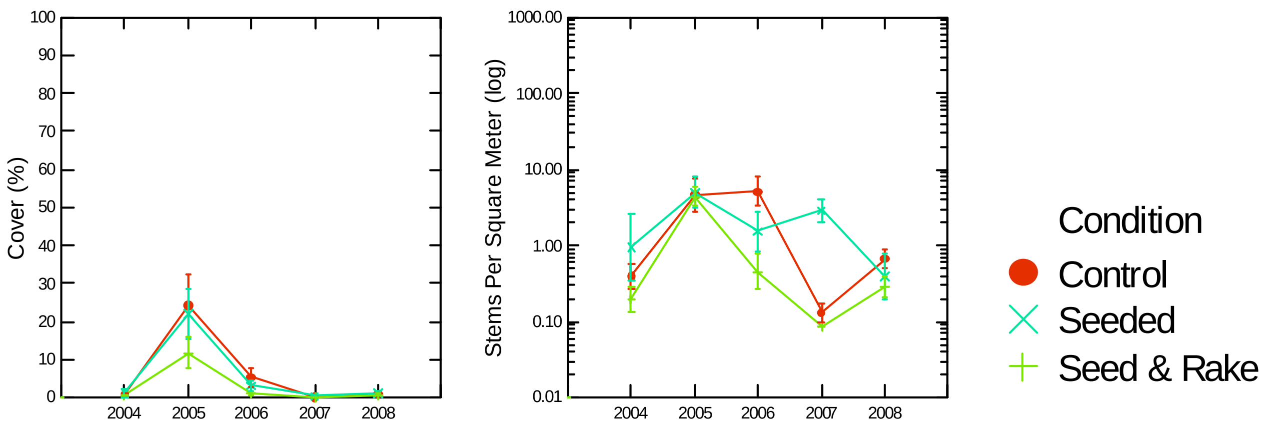

Figure 5. Mean cover and stem density (± SE) of non-native herbaceous species (grasses and forbs) in three postfire conditions in Pine Valley Meadow, Arizona.

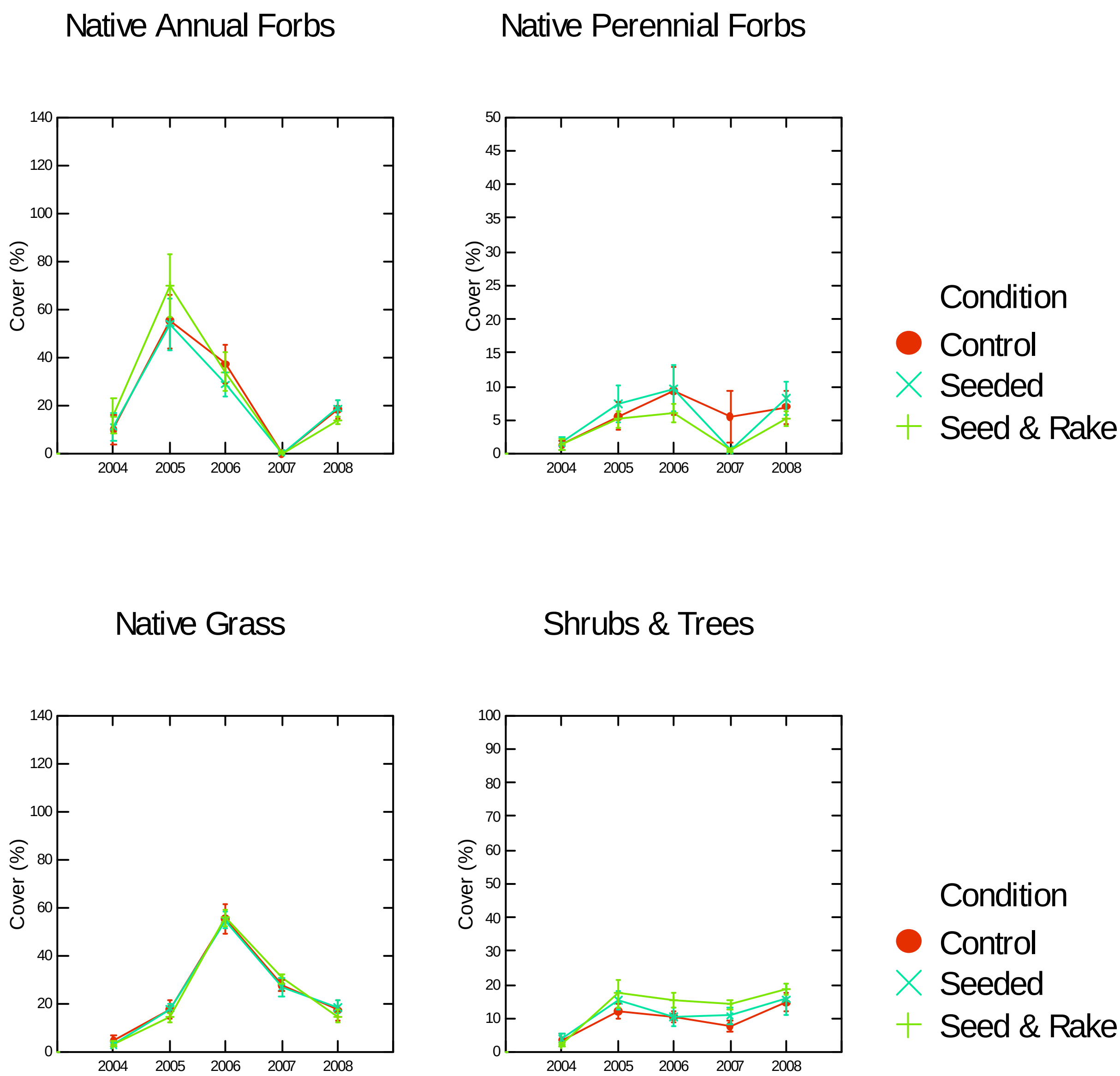

Figure 6. Mean absolute cover (± SE) of four guilds of native plant species in Pine Valley Meadow, Arizona.

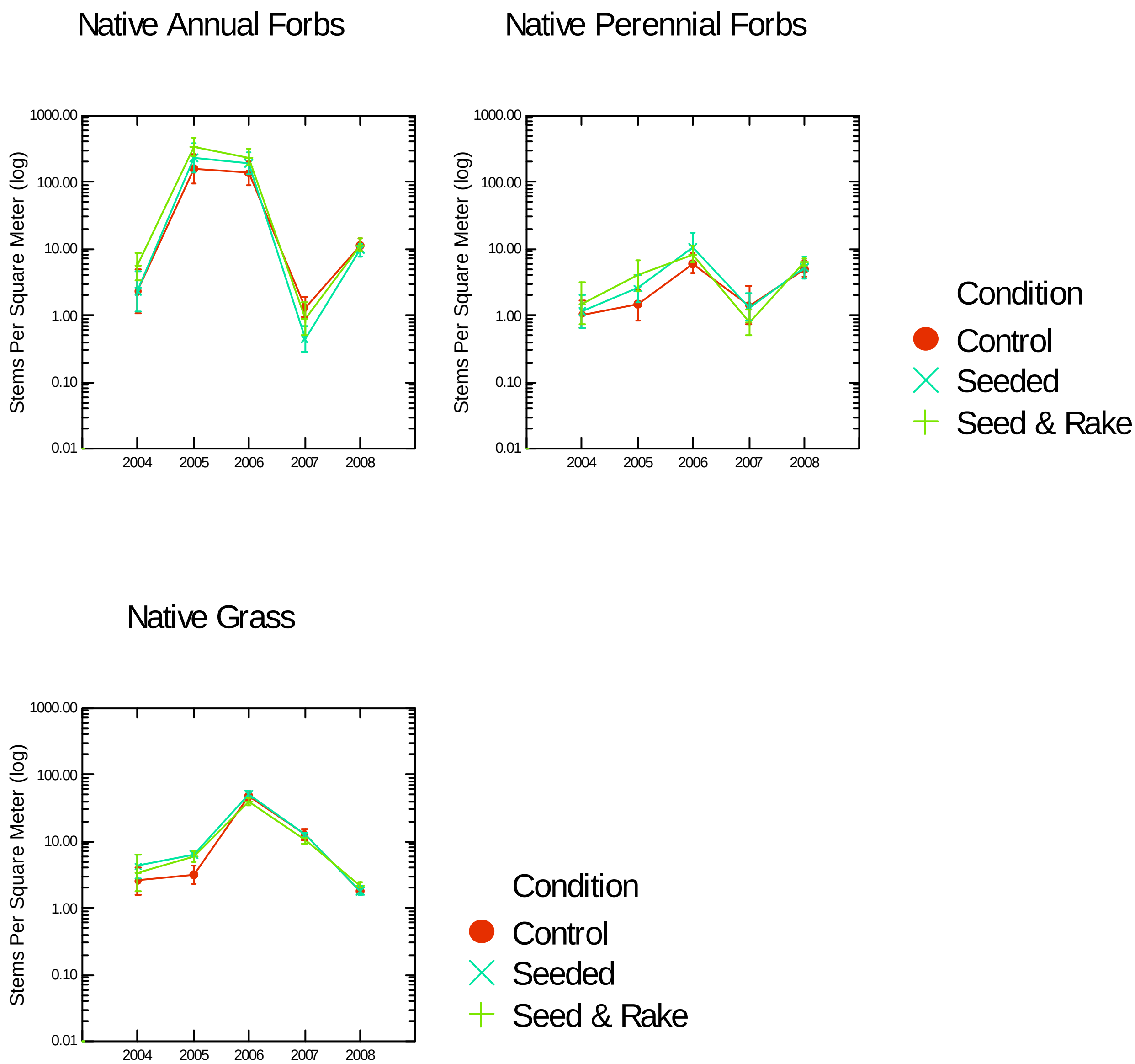

Figure 7. Mean stem density (± SE) of native herbaceous plant species in Pine Valley Meadow, Arizona.

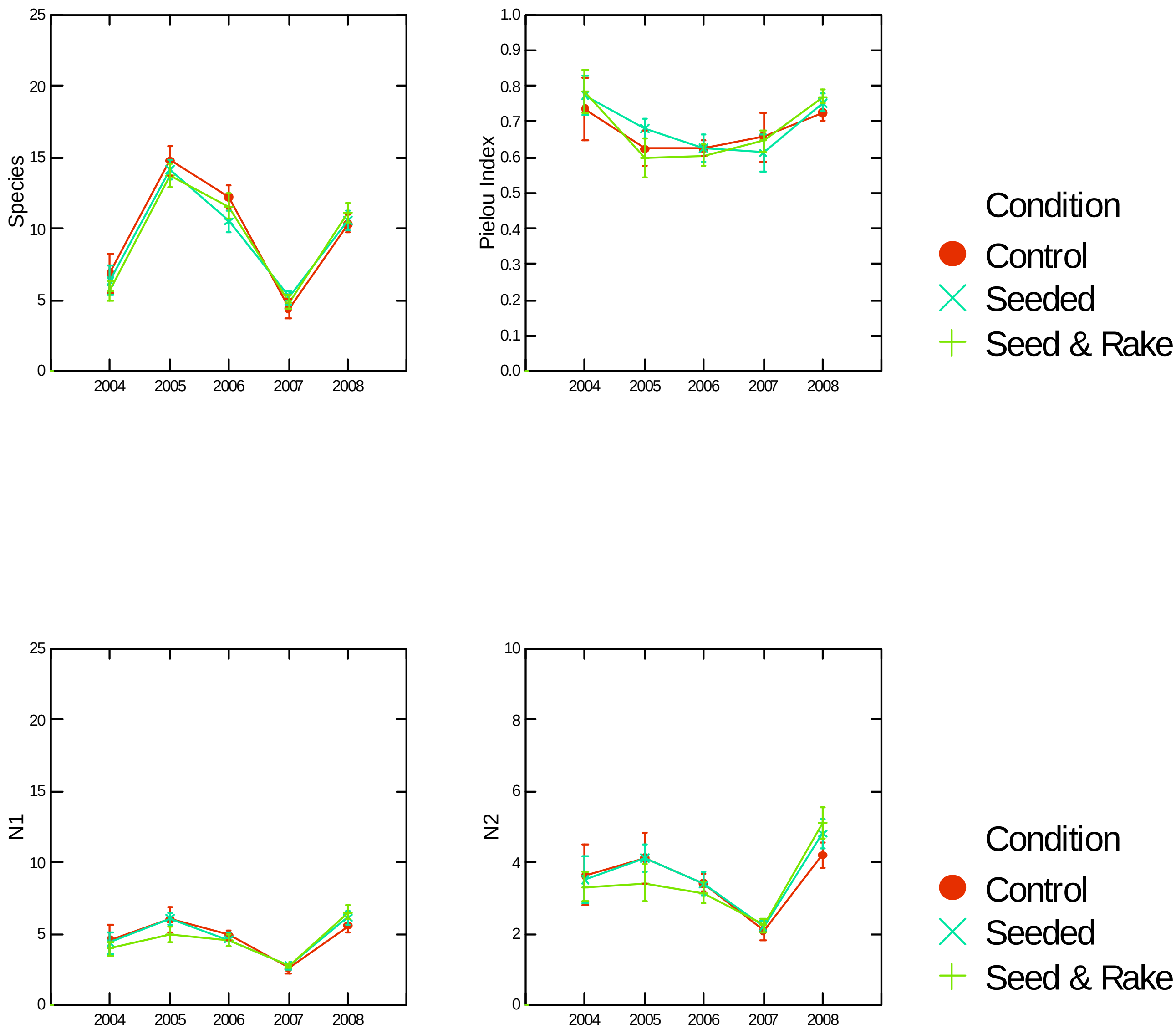

Figure 8. Mean values of four diversity indices (± SE) for a community comprised of native and alien plant species in Pine Valley Meadow, Arizona. The indices were derived from cover estimates. Pielou is an index of evenness, N1 the exponentiation of Shannon 's index, and N2 the reciprocal of Simpson's index of concentration.

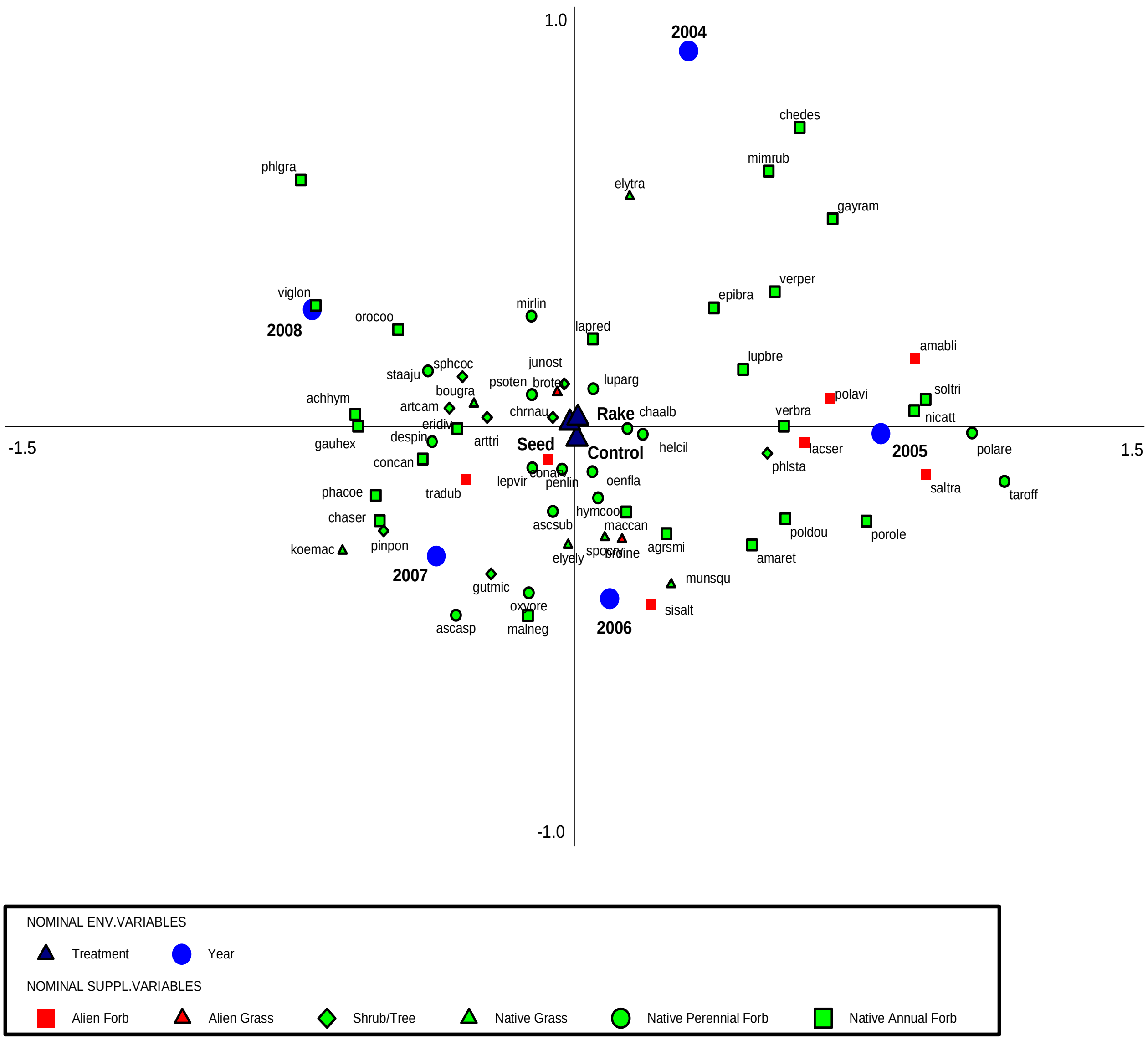

Figure 9. Distance-based redundancy analysis of the effects of postfire treatment conditions (control, seeded, seeded and raked) and inter-annual variation (2004 to 2008) on distribution and abundance patterns for 64 plant species at Pine Valley Meadow, Arizona.

Soil Seedbank

A total of 32 species occurred in the seedbank samples, 68% of which were native (Appendix A – Table 3). Native perennial grasses comprised a mean of 67% of the soil seedbank, while cheatgrass (the only non-native annual grass in the samples) comprised 22%. Of the two seeded species, bottlebrush squirreltail comprised 49% of the soil seedbank, whereas blue grama did not occur in any of the samples. Bottlebrush squirreltail seed density increased dramatically between 2004 and 2006 from initial conditions immediately following the fire in 2003 of being virtually absent from the plots (Figure 10), but was not affected significantly by seeding or raking treatments (Appendix B, Table 9). Cheatgrass showed an increase in seed density between 2003 and 2004 (Figure 11), but there was no significant difference in trajectories among treatments (Appendix B, Table 10).

There was no significant difference in species composition of the soil seedbank among the treatments (R = -0.023, P = 0.853), but there were major shifts in composition between 2003 and 2006 (R = 0.593, P = 0.001). Between six and nine species accounted for over 90% of the differences in species composition among years (Appendix B, Table 11). There were relatively small and variable numbers of cheatgrass seeds in the samples which began at approximately 1.1 seeds (per 18 cubic cm of soil) immediately following the fire in fall 2003 and only increased to 1.5 seeds in the fall of the third postfire year (Figure 11). However, cheatgrass seeds accounted for over 24% of the difference in species composition between 2003 and 2004 and contributed to differences in species composition in 2005 and 2006 (15.7% and 4.1%, respectively). The species primarily responsible for shifts in species composition from the 2003 baseline to 2005 and 2006 was bottlebrush squirreltail (20.7% and 59.5%, respectively; Appendix B, Table 11).

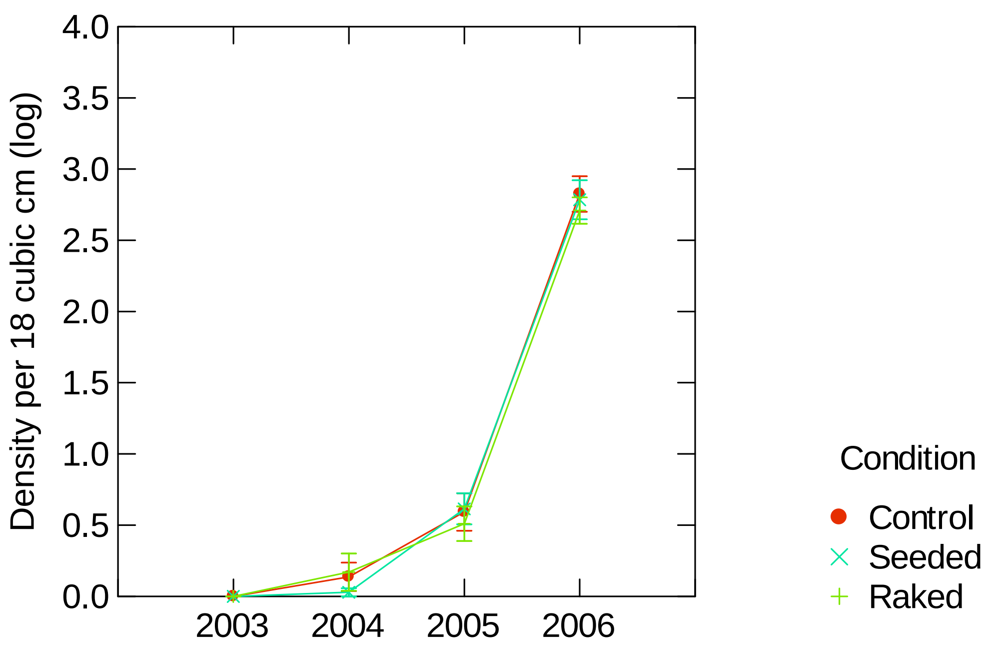

Figure 10. The mean density (± SE) of bottlebrush squirreltail *Elymus elymoides* seeds ($\log_e$ transformed) that germinated from soil seedbank samples in three conditions at Pine Valley Meadow, 2003-2006. Control plots were unseeded and unraked, Raked plots were seeded and raked, and Seeded plots were seeded only.

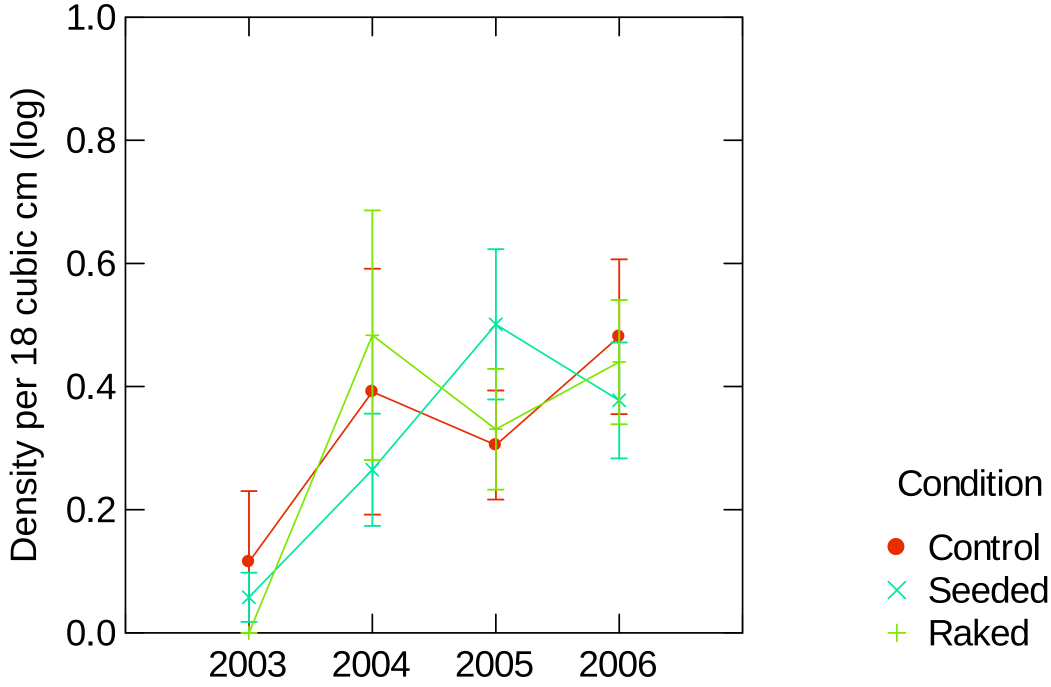

Figure 11. The density of cheatgrass *Bromus tectorum* seeds ($\log_e$ transformed) that germinated from soil seedbank samples in three conditions at Pine Valley Meadow, 2003-2006. Control plots were unseeded and unraked, Raked plots were seeded and raked, and Seeded plots were seeded only.

Key Findings

Seeding with or without raking had no detectable effects on any of the species or groups of species in this study as measured by: 1) the density, cover, and species diversity of standing vegetation during the first 5 post-treatment years; or 2) the density and species diversity of the soil seedbank during the first 3 post-treatment years. This lack of seeding effect occurred even under seemingly good conditions of seeding within a month following the fire and with one inch of rainfall occurring 2 weeks following the seeding. It is possible that seeding rates were small relative to the density of seeds that were present in untreated plots during this study. It is also possible that the timing and amount of subsequent rainfall were insufficient to support to maturity any seeds that may have initially germinated. Both of these factors can contribute to seedings not leading to detectable effects.

Blue grama had an overall low standing density and cover, and seedbank density, at the study site, whereas bottlebrush squirreltail had relatively high standing density and cover, and seedbank density, at least during some of the sampling years. Although seeding treatments did not increase the abundance of these species, bottlebrush squirreltail did appear to recover very well on its own following fire as follows:

- First post-treatment year (2004) – low standing density and cover, and low seedbank density
- Second post-treatment year (2005) – slightly increased standing density and cover, and increased seedbank density
- Third post-treatment year (2006) – greatly increased standing density and cover and greatly increased soil seedbank density, probably associated with very high rainfall prior to the growing season
- Fourth post-treatment year (2007) – standing density and cover less than previous year
- Fifth post-treatment year (2008) – standing density and cover back to 2005 levels, but cover remaining at approximately 10% (interpreted as individuals established during 2005-2006 remaining as adult plants).

Cheatgrass did not differ among treatments, including raked and unraked plots, and only increased from 1.1 seeds per 18 cubic cm of soil immediately following the fire in fall 2003 to 1.5 seeds by the fall of the third postfire year. Interestingly, the cheatgrass population did not increase episodically following fire, nor was it significantly affected by sampling year, as might be expected for an annual plant species. Rather, it increased steadily from initial conditions immediately after the fire to slightly higher levels by the third postfire year. Cheatgrass has been observed to occur in locally dense stands in the vicinity of the study area, but these areas are often associated with past disturbances such as logging operations (M. Brooks personal observation). Open meadows within the larger surrounding ponderosa pine forest might also be expected to be one of the more conducive places on the landscape for cheatgrass growth due to the deep silty soils, ample light, and relatively high soil moisture levels that occur in those areas. The reason for low cheatgrass abundance may not have been due to site conditions, but rather due to a local population crash caused by mortality from the fire. The early October fire occurred after a large cohort of cheatgrass had germinated and grown into seedlings in response to a pulse of rainfall during August and September (Figure 2), but before these plants had set seed. Mortality of these plants may have reduced population levels to the point that recovery to pre-fire levels will require many years. Fire conducted early in the growing season before plants have set seed (at the so-called "dough stage" for cheatgrass) has been suggested to be an effective control technique for invasive plants (DiTomaso et al. 2006). However, this recommendation is generally taken to mean a late spring burn following germination during the preceding winter. Cheatgrass can also germinate after summer rains and produce a significant fall crop that either sets seed before winter, or might overwinter as seedlings. In either case summer/fall cohorts may be vulnerable to fire treatments applied during the fall.

Management Implications

- Blue grama may be an inappropriate species for seeding at this study site, both because it did not establish from seeding treatments and because it was virtually absent from the soil seedbank during the course of this study.

- Bottlebrush squirreltail appears to be an appropriate species for seeding at this study site. This conclusion is not because it established from the seeding treatments, but because the seeds of this species appeared to be present in the soil seedbank immediately following the October 2003 fire and it appeared to recover on its own within a few postfire years.

- Cheatgrass may not be a significant postfire management concern at this study site because it did not increase in abundance appreciably during the first 3 postfire years of this study, although this might not have been the case if the fire occurred during summer when cheatgrass seeds were dormant in the soil seedbank and resistant to mortality from fire.

- Even under good conditions of seeding within a month of burning and appreciable rainfall occurring 2 weeks later seeding at this site may not be effective using the methods evaluated in this study. However, if Bottlebrush squirreltail can recover on its own within a few years, and especially if cheatgrass is slow to recover (at least following fall burn), then seeding might not be warranted anyway.

Future Research and Monitoring Needs

- Although the seeding treatments in this study did not demonstrate any detectable effects, this does not definitively mean that seedings (of bottlebrush squirreltail in particular) cannot be effective at this site. Additional studies evaluating the timing of seedings and seeding rates would be helpful.

- Seeding establishment rates and cheatgrass abundance can vary widely among years of contrasting rainfall. More trials need to be conducted under differing conditions to understand how variable these responses can be.

- Appropriately timed fire may be an effective way to achieve both cheatgrass control and fire management objectives for ponderosa pine forest in the Colorado Plateau. However, additional studies comparing spring, summer, and fall fires in other locations and during other years are needed to confirm this hypothesis.

Deliverables

Deliverables Listed in the Original Proposal
Year 1 progress report – delivered to the JFSP in September 2006
Year 2 progress report – delivered to the JFSP in September 2007
Final Report – delivered to the JFSP in March, 2010

Integrate preliminary results into NAFRI FIEM course – results from this study were integrated into this course when taught during Spring 2007, 2008, and 2009
Field workshop at the demonstration site – completed in June 2008
Peer-reviewed journal article and publication brief – currently in preparation and will be submitted for publication by 30 September, 2010
Fact sheets and other interpretive information – currently in preparation and will be completed by 30 June, 2010
Project website – *http://www.werc.usgs.gov/Project.aspx?ProjectID=100* completed in January, 2010
Additional Deliverables Not Listed in the Original Proposal
A fifth year of post-treatment vegetation data and a fourth year of post-treatment seedbank data (see Table 1)
Analysis of the NPS fire effects (FMH) database for prescribed burns in the ponderosa pine forest – completed in June 2008
Peer-reviewed journal article summarizing the history of fire management on the Shivwitz Plateau and the current vegetation and fuelbed conditions that have resulted – currently in preparation and will be submitted for publication during FY10
Information from this project has been integrated into 5 training sessions for fire managers, 9 invited presentations, and 2 contributed conference presentations.

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Appendix A – Species Lists

Table 2. Species recorded at plots in Pine Valley Meadow, Arizona, 2004-2008.

Species	Family	Origin	Life History	Life Form
Achnatherum hymenoides	Poaceae	Native	Perennial	Grass
Agoseris heterophylla	Asteraceae	Native	Annual	Forb
Agropyron smithii	Poaceae	Native	Perennial	Grass
Allium bisceptrum	Liliacaea	Native	Perennial	Forb
Amaranthus blitoides	Amaranthaceae	Alien	Annual	Forb
Amaranthus retroflexsis	Amaranthaceae	Native	Annual	Forb
Artemisia campestris	Asteraceae	Native	Perennial	Shrub
Artemisia tridentata	Asteraceae	Native	Perennial	Shrub
Asclepias asperula	Asclepiadaceae	Native	Perennial	Forb
Asclepias subverticillata	Asclepiadaceae	Native	Perennial	Forb
Bouteloua gracilis	Poaceae	Native	Perennial	Grass
Bromus inermis	Poaceae	Alien	Perennial	Grass
Bromus tectorum	Poaceae	Alien	Annual	Grass
Castilleja linaeiifolia	Scrophulariaceae	Native	Perennial	Forb
Chamaesyce albomarginata	Euphorbiaceae	Native	Perennial	Forb
Chamaesyce serpyllifolia	Euphorbiaceae	Native	Annual	Forb
Chenopidium desiccatum	Chenopodiaceae	Native	Annual	Forb
Chenopodium album	Chenopodiaceae	Alien	Annual	Forb
Chrysothamnus nauseosus	Asteraceae	Native	Perennial	Shrub
Convolvulus arvensis	Convolvulaceae	Alien	Perennial	Forb
Conyza canadensis	Asteraceae	Native	Annual	Forb
Dalea searlsiae	Fabaceae	Native	Perennial	Forb
Elymus elymoides	Poaceae	Native	Perennial	Grass
Elymus trachycaulus	Poaceae	Native	Perennial	Grass
Epilobium brachycarpum	Onagraceae	Native	Annual	Forb
Erigeron divergens	Asteraceae	Native	Annual	Forb
Eriogonum racemosum	Polygonaceae	Native	Perennial	Forb
Erodium cicutarium	Geraniaceae	Alien	Annual	Forb
Gayophytum ramosissimum	Onagraceae	Native	Annual	Forb
Gutierrezia microcephala	Asteraceae	Native	Perennial	Shrub
Helianthus annuus	Asteraceae	Native	Annual	Forb
Helianthus ciliaris	Asteraceae	Native	Perennial	Forb
Hymenopappus filifolius	Asteraceae	Native	Perennial	Forb
Hymenoxys cooperi	Asteraceae	Native	Perennial	Forb
Juniperus osteosperma	Cupressaceae	Native	Perennial	Tree
Koeleria macrantha	Poaceae	Native	Perennial	Grass
Lactuca serriola	Asteraceae	Alien	Annual	Forb
Lappula redowskii	Boraginaceae	Native	Annual	Forb
Lepidium virginicum	Brassicaceae	Native	Perennial	Forb
Lotus wrightii	Fabaceae	Native	Annual	Forb
Lupinus argenteus var utahensis	Fabaceae	Native	Perennial	Forb
Lupinus brevicaulis	Fabaceae	Native	Annual	Forb
Machaeranthera canescens	Asteraceae	Native	Annual	Forb

Table 2. continued.

Species	Family	Origin	Life History	Life Form
Malva neglecta	Malvaceae	Native	Annual	Forb
Metzelia albicaulis	Loasaceae	Native	Annual	Forb
Mimulus rubellus	Scrophulariaceae	Native	Annual	Forb
Mirabilis linearis	Nyctaginaceae	Native	Perennial	Forb
Munroa squarrosa	Poaceae	Native	Annual	Grass
Nicotiana attenuata	Solanaceae	Native	Annual	Forb
Oenothera flava	Onagraceae	Native	Perennial	Forb
Opuntia littoralis	Cactaceae	Native	Perennial	Shrub
Penstemon barbatus	Scrophulariaceae	Native	Perennial	Forb
Penstemon linariodes	Scrophulariaceae	Native	Perennial	Forb
Phlox gracilis	Polemoniaceae	Native	Annual	Forb
Phlox stansburyi	Polemoniaceae	Native	Perennial	Shrub
Pinus ponderosa	Pinaceae	Native	Perennial	Tree
Polygonum aviculare	Polygonaceae	Alien	Annual	Forb
Polygonum douglasii	Polygonaceae	Native	Annual	Forb
Portulaca oleracea	Portulacaceae	Native	Annual	Forb
Psoralidium tenuiflorum	Fabaceae	Native	Perennial	Forb
Salsola tragus	Chenopodiaceae	Alien	Annual	Forb
Sisymbrium altissimum	Brassicaceae	Alien	Annual	Forb
Solanum jamesii	Solanaceae	Native	Perennial	Forb
Solanum triflorum	Solanaceae	Native	Annual	Forb
Sphaeralcea ambigua	Malvaceae	Native	Perennial	Shrub
Sphaeralcea coccinea	Malvaceae	Native	Perennial	Shrub
Sporobolus cyrptandrus	Poaceae	Native	Perennial	Grass
Stachys ajugoides	Lamiaceae	Native	Perennial	Forb
Taraxacum officinale	Asteraceae	Native	Perennial	Forb
Tragopogon dubius	Asteraceae	Alien	Annual	Forb
Verbena bracteata	Verbenaceae	Native	Annual	Forb
Veronica peregrina	Scrophulariaceae	Native	Annual	Forb

Table 3. Plant species that germinated in soil seed bank samples from Pine Valley Meadow, 2003-2006..

Species	Acronym	Origin	Life History	Life Form
Amaranthus blitoides	amabli	Alien	Annual	Forb
Amaranthus retroflexsis	amaret	Native	Annual	Forb
Artemisia tridentata	arttri	Native	Perennial	Shrub
Bromus tectorum	brotec	Alien	Annual	Grass
Capsella bursa	capbur	Alien	Annual	Forb
Chamaesyce serpyllifolia	chaser	Native	Annual	Forb
Chenopidium desiccatum	chedes	Native	Annual	Forb
Conyza canadensis	concan	Native	Annual	Forb
Descurainia obtusa	desobt	Native	Annual	Forb
Draba cuneifolia	dracun	Native	Annual	Forb
Draba parryi	drapar	Native	Annual	Forb
Elymus elymoides	elyely	Native	Perennial	Grass
Erigeron divergens	eridiv	Native	Annual	Forb
Erodium cicutarium	erocic	Alien	Annual	Forb
Gayophytum ramosissimum	gayram	Native	Annual	Forb
Lactuca serriola	lacser	Alien	Annual	Forb
Lappula redowskii	lapred	Native	Annual	Forb
Lepidium lasiocarpum	leplas	Native	Annual	Forb
Lepidium virginicum	lepvir	Native	Perennial	Forb
Monolepis nuttalliana	monnut	Native	Annual	Forb
Nicotiana attenuata	nicatt	Native	Annual	Forb
Phlox gracilis	phlgra	Native	Annual	Forb
Polygonum arenastrum	polare	Native	Perennial	Forb
Polygonum douglasii	poldou	Native	Annual	Forb
Portulaca oleracea	porole	Native	Annual	Forb
Sporobolus cyrptandrus	spocry	Native	Perennial	Grass
Sporobolus neglectus	sponeg	Native	Annual	Grass
Taraxacum officinale	taroff	Native	Perennial	Forb
Tragopogon dubius	tradub	Alien	Annual	Forb
Veronica peregrina	verper	Native	Annual	Forb
Verbascum thapsus	vertha	Alien	Perennial	Forb
Vulpia octoflora	vuloct	Native	Annual	Grass

Appendix B – Statistical Test Results

Table 4. ANOVA results of the response of two species of native grass in post-fire treatments (control, seeded, seeded and raked) across five years (2004-2008) at Pine Valley Meadow, Arizona. The analysis was based on hierarchical linear models with block as a random effect. The response variables were total percent cover and stem density (stems m^{-2}). All response variables were (log+1 transformed).

Cover (%)

Analysis of Variance

Source	Type III SS	Numerator df	Denominator df	Mean Squares	F-ratio	p-value
Treatment	114.266	2	161.000	57.133	1.088	0.339
Year	39559.758	4	161.000	9889.939	188.291	0.000
Treatment*Year	366.021	8	161.000	45.753	0.871	0.542
Block	3727.571	6	161.000	621.262	11.828	0.000
Error	8456.496		161	52.525		

Estimates of Variance Components

Source	Variance Components	Standard Error	Z	p-value	95% C. I.	
					Lower	Upper
Block	27.214	17.337	1.570	0.116	-6.766	61.193
Error	52.525	6.025	8.718	0.000	40.716	64.333

Stem Density

Analysis of Variance

Source	Type III SS	Numerator df	Denominator df	Mean Squares	F-ratio	p-value
Treatment	0.040	2	162.000	0.020	0.735	0.481
Year	32.455	4	162.000	8.114	294.800	0.000
Treatment*Year	0.317	8	162.000	0.040	1.439	0.184
Block	3.551	6	162.000	0.592	21.504	0.000
Error	4.459		162	0.028		

Estimates of Variance Components

Source	Variance Components	Standard Error	Z	p-value	95% C. I.	
					Lower	Upper
Block	0.027	0.016	1.642	0.101	-0.005	0.059
Error	0.028	0.003	8.746	0.000	0.021	0.034

Table 5. ANOVA results of the response of five guilds of plants in Pine Valley Meadow, Arizona, to post-fire treatments (control, seeded, seeded and raked) across five years (2004-2008). The analysis was based on hierarchical linear models with block as a random effect. The response variable was total percent cover (log+1 transformed) per sampling plot.

Non-native Herbaceous Species

Analysis of Variance

Source	Type III SS	Numerator df	Denominator df	Mean Squares	F-ratio	p-value
Treatment	0.060	2	161.000	0.030	0.381	0.684
Year	22.098	4	161.000	5.525	70.433	0.000
Treatment*Year	0.629	8	161.000	0.079	1.002	0.437
Block	3.151	6	161.000	0.525	6.695	0.000
Error	12.628		161	0.078		

Estimates of Variance Components

Source	Variance Components	Standard Error	Z	p-value	95% C. I.	
					Lower	Upper
Block	0.021	0.015	1.449	0.147	-0.008	0.050
Error	0.078	0.009	8.718	0.000	0.061	0.096

Native Annual Forbs

Analysis of Variance

Source	Type III SS	Numerator df	Denominator df	Mean Squares	F-ratio	p-value
Treatment	0.046	2	161.000	0.023	0.243	0.784
Year	55.139	4	161.000	13.785	145.812	0.000
Treatment*Year	0.308	8	161.000	0.039	0.407	0.915
Block	0.645	6	161.000	0.107	1.137	0.343
Error	15.221		161	0.095		

Estimates of Variance Components

Source	Variance Components	Standard Error	Z	p-value	95% C. I.	
					Lower	Upper
Block	0.001	0.003	0.215	0.830	-0.005	0.006
Error	0.095	0.011	8.738	0.000	0.073	0.116

Table 5 continued.

Native Perennial Forbs

Analysis of Variance

Source	Type III SS	Numerator df	Denominator df	Mean Squares	F-ratio	p-value
Treatment	0.002	2	161.000	0.001	0.010	0.990
Year	8.801	4	161.000	2.200	23.612	0.000
Treatment*Year	0.346	8	161.000	0.043	0.464	0.880
Block	9.219	6	161.000	1.536	16.487	0.000
Error	15.004		161	0.093		

Estimates of Variance Components

Source	Variance Components	Standard Error	Z	p-value	95% C. I.	
					Lower	Upper
Block	0.069	0.043	1.615	0.106	-0.015	0.153
Error	0.093	0.011	8.718	0.000	0.072	0.114

Native Grass

Analysis of Variance

Source	Type III SS	Numerator df	Denominator df	Mean Squares	F-ratio	p-value
Treatment	0.001	2	161.000	0.000	0.013	0.988
Year	18.327	4	161.000	4.582	119.689	0.000
Treatment*Year	0.174	8	161.000	0.022	0.568	0.803
Block	0.982	6	161.000	0.164	4.276	0.001
Error	6.163		161	0.038		

Estimates of Variance Components

Source	Variance Components	Standard Error	Z	p-value	95% C. I.	
					Lower	Upper
Block	0.006	0.005	1.297	0.195	-0.003	0.015
Error	0.038	0.004	8.719	0.000	0.030	0.047

Shrubs and Trees

Analysis of Variance

Source	Type III SS	Numerator df	Denominator df	Mean Squares	F-ratio	p-value
Treatment	157.314	2	161.000	78.657	1.415	0.246
Year	2441.402	4	161.000	610.350	10.982	0.000
Treatment*Year	180.141	8	161.000	22.518	0.405	0.916
Block	1610.863	6	161.000	268.477	4.830	0.000
Error	8948.328		161	55.580		

Estimates of Variance Components

Source	Variance Components	Standard Error	Z	p-value	95% C. I.	
					Lower	Upper
Block	10.187	7.577	1.344	0.179	-4.664	25.038
Error	55.580	6.375	8.719	0.000	43.085	68.074

Table 6. ANOVA results of the response of four guilds of plants in Pine Valley Meadow, Arizona, to post-fire treatments (control, seeded, seeded and raked) across five years (2004-2008). The analysis was based on hierarchical linear models with block as a random effect. The response variable was total stem density (log+1 transformed) per sampling plot.

Non-native Herbaceous Species

Analysis of Variance

Source	Type III SS	Numerator df	Denominator df	Mean Squares	F-ratio	p-value
Treatment	0.220	2	162.000	0.110	1.285	0.279
Year	13.217	4	162.000	3.304	38.627	0.000
Treatment*Year	1.338	8	162.000	0.167	1.955	0.055
Block	2.337	6	162.000	0.389	4.553	0.000
Error	13.857		162	0.086		

Estimates of Variance Components

Source	Variance Components	Standard Error	Z	p-value	95% C. I.	
					Lower	Upper
Block	0.014	0.011	1.321	0.186	-0.007	0.036
Error	0.086	0.010	8.747	0.000	0.066	0.105

Native Annual Forbs

Analysis of Variance

Source	Type III SS	Numerator df	Denominator df	Mean Squares	F-ratio	p-value
Treatment	0.360	2	162.000	0.180	1.329	0.268
Year	155.783	4	162.000	38.946	287.659	0.000
Treatment*Year	0.583	8	162.000	0.073	0.538	0.827
Block	6.548	6	162.000	1.091	8.061	0.000
Error	21.933		162	0.135		

Estimates of Variance Components

Source	Variance Components	Standard Error	Z	p-value	95% C. I.	
					Lower	Upper
Block	0.046	0.030	1.495	0.135	-0.014	0.105
Error	0.135	0.015	8.747	0.000	0.105	0.166

Table 6 continued.

Native Perennial Forbs

Analysis of Variance

Source	Type III SS	Numerator df	Denominator df	Mean Squares	F-ratio	p-value
Treatment	0.854	2	162.000	0.427	3.664	0.028
Year	8.701	4	162.000	2.175	18.657	0.000
Treatment*Year	0.529	8	162.000	0.066	0.567	0.804
Block	6.609	6	162.000	1.102	9.448	0.000
Error	18.888		162	0.117		

Estimates of Variance Components

Source	Variance Components	Standard Error	Z	p-value	95% C. I. Lower	95% C. I. Upper
Block	0.047	0.031	1.529	0.126	-0.013	0.107
Error	0.117	0.013	8.747	0.000	0.090	0.143

Native Grass

Analysis of Variance

Source	Type III SS	Numerator df	Denominator df	Mean Squares	F-ratio	p-value
Treatment	0.272	2	162.000	0.136	2.840	0.061
Year	29.837	4	162.000	7.459	155.514	0.000
Treatment*Year	0.378	8	162.000	0.047	0.984	0.450
Block	0.444	6	162.000	0.074	1.544	0.167
Error	7.770		162	0.048		

Estimates of Variance Components

Source	Variance Components	Standard Error	Z	p-value	95% C. I. Lower	95% C. I. Upper
Block	0.001	0.002	0.600	0.548	-0.003	0.005
Error	0.048	0.005	8.756	0.000	0.037	0.059

Table 7. ANOVA results of changes in four measures of plant diversity to post-fire treatments (control, seeded, seeded and raked) across five years (2004-2008) in Pine Valley Meadow, Arizona. The analysis was based on hierarchical linear models with block as a random effect. The response variables were total species richness, N1 (the exponentiation of Shannon 's index), N2 (the reciprocal of Simpson's index of concentration), and Pielou's index of evenness.

Species Richness

Analysis of Variance

Source	Type III SS	Numerator df	Denominator df	Mean Squares	F-ratio	p-value
Treatment	1.213	2	161.000	0.607	0.174	0.840
Year	1906.492	4	161.000	476.623	136.757	0.000
Treatment*Year	31.254	8	161.000	3.907	1.121	0.352
Block	294.933	6	161.000	49.156	14.104	0.000
Error	561.112		161	3.485		

Estimates of Variance Components

Source	Variance Components	Standard Error	Z	p-value	95% C. I.	
					Lower	Upper
Block	2.185	1.370	1.595	0.111	-0.499	4.870
Error	3.485	0.400	8.718	0.000	2.702	4.269

N1

Analysis of Variance

Source	Type III SS	Numerator df	Denominator df	Mean Squares	F-ratio	p-value
Treatment	0.609	2	161.000	0.304	0.188	0.829
Year	242.372	4	161.000	60.593	37.401	0.000
Treatment*Year	16.036	8	161.000	2.004	1.237	0.281
Block	99.059	6	161.000	16.510	10.191	0.000
Error	260.832		161	1.620		

Estimates of Variance Components

Source	Variance Components	Standard Error	Z	p-value	95% C. I.	
					Lower	Upper
Block	0.712	0.461	1.544	0.123	-0.192	1.617
Error	1.620	0.186	8.718	0.000	1.256	1.984

Table 7 continued.

N2

Analysis of Variance

Source	Type III SS	Numerator df	Denominator df	Mean Squares	F-ratio	p-value
Treatment	0.128	2	161.000	0.064	0.053	0.949
Year	119.810	4	161.000	29.953	24.665	0.000
Treatment*Year	9.384	8	161.000	1.173	0.966	0.465
Block	55.199	6	161.000	9.200	7.576	0.000
Error	195.517		161	1.214		

Estimates of Variance Components

Source	Variance Components	Standard Error	Z	p-value	95% C. I. Lower	95% C. I. Upper
Block	0.382	0.258	1.481	0.139	-0.124	0.888
Error	1.214	0.139	8.718	0.000	0.941	1.487

Pielou's Index

Analysis of Variance

Source	Type III SS	Numerator df	Denominator df	Mean Squares	F-ratio	p-value
Treatment	0.008	2	161.000	0.004	0.296	0.744
Year	0.565	4	161.000	0.141	10.833	0.000
Treatment*Year	0.074	8	161.000	0.009	0.707	0.685
Block	0.494	6	161.000	0.082	6.311	0.000
Error	2.101		161	0.013		

Estimates of Variance Components

Source	Variance Components	Standard Error	Z	p-value	95% C. I. Lower	95% C. I. Upper
Block	0.003	0.002	1.432	0.152	-0.001	0.008
Error	0.013	0.001	8.718	0.000	0.010	0.016

Table 8. Results from a distance-based redundancy analysis of the effects of postfire treatments (control, seeded, seeded and raked) and interannual variation (2004 to 2008) on plant species composition at Pine Valley Meadow, Arizona. E = the eigenvalue (raw variance) of the axes.

Variable	Axis 1	Axis 2
Control	0.0076	-0.0555
Seeded	-0.0192	0.0161
Seeded and Raked	0.0117	-0.0391
2004	0.1964	0.7797
2005	0.7984	-0.0220
2006	0.0907	-0.5400
2007	-0.3554	-0.3988
2008	-0.6859	0.3670
E	0.293	0.166
Species/Environment Correlation	0.928	0.823
Cumulative Variance Species Data (%)	33.0	51.6
Cumulative Variance Species-Environmental (%)	48.6	76.1

Table 9. Hierarchical model statistics of the density of bottlebrush squirreletail seeds ($\log_e$ transformed) that germinated from soil seed bank samples collected at Pine Valley Meadow from 2003 through 2006. Percent is the percent of variation accounted for by each random factor.

Fixed Factors	**Estimate**	**SE**	**Z**	***P***	
Constant	0.123	0.183	0.672	0.251	
Year	-0.799	0.200	3.995	0.000	
$Year^2$	0.568	0.060	9.467	0.000	
Seeding	-0.081	0.211	0.384	0.350	
Raking	-0.030	0.211	0.142	0.444	
Seeding*Raking	0.000	0.000	0.000	1.000	
Year*Seeding	-0.013	0.276	0.047	0.481	
Year*Raking	0.009	0.276	0.033	0.487	
$Year^2$*Seeding	0.002	0.083	0.024	0.490	
$Year^2$*Raking	-0.015	0.083	0.181	0.428	
Year*Seeding*Raking	0.000	0.000	0.000	1.000	
$Year^2$*Seeding*Raking	0.000	0.000	0.000	1.000	
Random Factors					**Percent**
Block	0.064	0.040	1.600	0.055	11.8
Plot	0.010	0.013	0.769	0.221	1.8
Error	0.468	0.034	13.765	0.000	86.3

Table 10. Hierarchical model statistics of the density of cheatgrass seeds ($\log_e$ transformed) that germinated from soil seed bank samples collected at Pine Valley Meadow from 2003 through 2006. Percent is the percent of variation accounted for by each random factor.

Fixed Factors	**Estimate**	**SE**	**Z**	***P***	
Constant	0.053	0.090	0.589	0.278	
Year	0.120	0.135	0.889	0.187	
$Year^2$	0.007	0.043	0.163	0.435	
Seeding	-0.062	0.127	0.488	0.313	
Raking	0.018	0.127	0.142	0.444	
Seeding*Raking	0.000	0.000	0.000	1.000	
Year*Seeding	0.192	0.192	1.000	0.159	
Year*Raking	-0.071	0.192	0.370	0.356	
$Year^2$*Seeding	-0.064	0.061	1.049	0.147	
$Year^2$*Raking	0.024	0.061	0.393	0.347	
Year*Seeding*Raking	0.000	0.000	0.000	1.000	
$Year^2$*Seeding*Raking	0.000	0.000	0.000	1.000	
Random Factors					**Percent**
Block	0.000	0.000	0.000	1.000	0.0
Plot	0.012	0.008	1.500	0.067	3.2
Error	0.359	0.022	16.318	0.000	96.8

Table 11. Similarity percentage (SIMPER) statistics for the density of seeds that germinated from soil seedbank samples collected in plots at Pine Valley Meadow from 2003 through 2006. *D* is the mean dissimilarity value for an individual species and was calculated from 999 bootstrap samples. Species acronyms are provided in Appendix A, Table 3.

2003 & 2004: mean dissimilarity = 77.99

	Years				Contribution (%)	
Species	**2003**	**2004**	***D***	***D/SD***	**Individual**	**Cumulative**
Brotec	0.17	2.00	19.0	0.98	24.4	24.4
Eridiv	0.47	0.38	12.0	0.95	15.4	39.7
Phlgra	0.45	0.32	11.9	0.64	15.2	55.0
Chedes	0.00	1.00	10.9	0.74	14.0	69.0
Arttri	0.27	0.19	7.4	0.81	9.5	78.4
Concan	0.00	0.22	5.9	0.48	7.5	85.9
Porole	0.05	0.07	3.1	0.56	3.9	89.9
Elyely	0.00	0.44	2.6	0.55	3.3	93.1

2003 & 2005: mean dissimilarity = 88.26

	Years				Contribution (%)	
Species	**2003**	**2005**	***D***	***D/SD***	**Individual**	**Cumulative**
Elyely	0.00	1.78	18.2	1.08	20.7	20.7
Phlgra	0.45	2.10	15.9	0.69	18.0	38.7
Brotec	0.17	1.23	13.8	0.95	15.7	54.3
Porole	0.05	1.17	11.2	0.65	12.7	67.0
Eridiv	0.47	0.33	6.0	0.74	6.8	73.9
Chedes	0.00	0.65	5.4	0.63	6.1	80.0
Arttri	0.27	0.15	5.0	0.63	5.6	85.6
Gayram	0.00	0.42	3.5	0.35	4.0	89.6
Verper	0.02	0.31	2.5	0.35	2.8	92.4

2003 & 2006: mean dissimilarity = 96.08

	Years				Contribution (%)	
Species	**2003**	**2006**	***D***	***D/SD***	**Individual**	**Cumulative**
Elyely	0.00	20.17	57.1	2.91	59.5	59.5
Chedes	0.00	5.04	15.1	1.29	15.7	75.2
Porole	0.05	1.92	5.4	0.98	5.6	80.8
Brotec	0.17	1.42	4.0	0.67	4.1	84.9
Concan	0.00	0.97	3.4	0.76	3.5	88.4
Phlgra	0.45	0.99	3.1	0.68	3.2	91.5