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Seed Bank Analysis Post Fuels-Reduction Treatments

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Abstract

Pinyon-Juniper (P-J) ecosystems are extensive throughout the western U.S. and have been expanding into shrublands and grasslands. A variety of tree-removal methods have been used in an attempt to restore herbaceous cover and reduce the risk of catastrophic fire with unknown effects on plant communities. I examined the impact of three different fuels reduction treatments on the local seed bank. The treatments were: mastication, where fuels are mulched and left in the plot; broadcast burn, where fuels are spread evenly across the plot and burned; and pile burn, where fuels are placed in discrete piles and burned. Treatments were adjacent to an untreated control site. The plot subjected to the pile burn treatment had a significantly higher seedling density ($P = 0.04$) than plot subjected to the broadcast burn treatment. Additionally, the plot subjected to the pile burn treatment had significantly higher species diversity ($P = 0.0004$) than the control. Artificial seeding, preformed by the Bureau of Land Management, had no effect on seedling density ($P > 0.05$), but did significantly lower species diversity ($P < 0.0001$). This study indicates that treatment, most notably the pile burn treatment, has an effect on seedling density and species diversity, while seeding only affected species diversity.

Introduction

Pinyon (*Pinus edulis and P. monophylla)* and juniper (*Juniperus spp.*) species dominate the lower elevation woodland ecosystems in the arid southwestern United States (Romme et al. 2009). Over the past 150 years, pinyon-juniper (P-J) woodlands have been expanding into adjacent plant communities and increasing tree density, which is also known as ‘thickening,’ thus reducing understory plant cover (Miller and Wigand 1994). This expansion and thickening has resulted in a lengthening of fire return intervals in some regions allowing these woodlands to further increase in density and thus reduce their susceptibility to more destructive crown fire (Miller et al. 2000; Miller and Tausch 2001). However, pinyon-juniper woodlands are now approaching later stages of growth, resulting in dense and contiguous canopies. These aging canopies lead to an increase in the continuity of crown fuels thus increasing their susceptibility to intense crown fires (Neary et al. 1999).

In order to restore understory herbaceous cover and reduce the risk of catastrophic crown fire, land managers are implementing a variety of tree removal strategies including mastication, where fuels are mulched and left in the plot; broadcast burn, where fuels are spread evenly across the plot and burned; and pile burn, where fuels are placed in discrete piles and burned. After actual fire or other fuels-reduction treatments, a large component of vegetation regeneration comes from the recruitment of seeds out of the soil seed bank (Putwain and Gillham 1990). However, the seed bank response to fire depends on how individual seeds are affected by conditions created both during and after a fire—such as high temperatures and changes in moisture—thus, increasing the importance of the applied tree removal strategy (Allen et al. 2008).

In order to determine the most successful tree removal strategy, the effects of the different treatment types on local seed banks have been studied. In a study on the effects of a spring prescribed burn (an artificial fire to clear overgrown woodland) on seed densities in the local seed bank, a decrease of perennial grass and shrub seeds relative to pre-burn densities was found, therefore limiting plant recruitment (Allen et al. 2008). Heat or severity of fire was the primary factor for lower emergence of seeds from the local seed bank, thus preventing regeneration (Allen et al. 2008). Different forms of management, such as mastication (the thinning of the tree canopy through mulching), may have different effects depending on the plant community type (Kane et al. 2010; Owen et al. 2009). One study comparing mastication treatment to pile burning in a P-J woodland found that plant composition in mastication plots deviated less from untreated plots than that in plots subjected to pile burning, suggesting a less detrimental effect of the former treatment on the local seed bank (Owen et al. 2009). However, there was significantly higher exotic plant cover, most notably *Bromus tectorum* in the pile burn treatment compared with plots subjected to mastication (Owen et al. 2009).

After the treatments, species that are sparse in the pre-treatment vegetation generally dominate early post-treatment vegetation (Everett and Ward 1984). Many of these early colonizers, the first germinants to grow in the newly treated area, are species found in the soil seed bank (Chambers and MacMahon 1994; Davis and Thompson 2000; Everett and Ward 1984). Knowledge of the density and composition of the soil seed bank after treatment is thus important for understanding post-disturbance vegetation composition (Allen et al. 2008).

Furthermore, the high cost of reseeding efforts after a prescribed treatment and the uncertainty regarding the effectiveness of these efforts, have led to interest in the capacity of the soil seed bank to promote vegetation recovery (Allen et al. 2008).

Local seed banks respond differently to treatments among various ecosystems and may be influenced by factors such as microsite distribution (e.g. shrub and tree canopies, canopy interspaces) and how seeds are dispersed throughout the environment (Allen et al. 2008; Chambers and MacMahon 1994). Seed dispersal may be characterized as occurring in two phases are dominated by different physical and biological processes. Phase I dispersal is any mechanism by which a seed moves, or is transported, from the parent plant to a surface (Chambers and MacMahon 1994). Phase II dispersal occurs after a seed has detached from its parent plant and has arrived on a surface from where it can subsequently either move to a new location via horizontal movement or integrate into the soil via vertical movement (Chambers and MacMahon 1994). Each phase can be influenced by abiotic (non-living forces) and biotic (living forces) factors such as wind, water, and animals, all of which thus affect seedling densities (Chambers and MacMahon 1994).

Seed density, the amount of seeds per unit area, within the soil seed bank can differ greatly among microsites (Huxman et al. 2004). This variation is partially due to abiotic influences on dispersal such as wind and water and also effects of soil surface microtopography (Huxman et al. 2004). Soil surface microtopography in semi-arid ecosystems consists of cracks, depressions, and channels, which allows interspace channels (areas with no vegetation) to form (Huxman et al. 2004). Wind-dispersed seeds can travel great distances before getting caught in these soil cracks, depressions, or litter beneath a shrub or tree, thereby creating unique seed banks (Chambers and Macmahon 1994; Huxman et al. 2004). To address this variability caused by different microsites, seedling densities must be adjusted based on the percent cover of the particular microsite the sample was collected from to determine the effect of the treatment on the overall site.

In this study, I address two questions related to the effects of three prescribed fuel-reduction treatments on the seed bank of P-J woodlands: 1) What are the effects of different treatments on the soil seed bank? and 2) What are the effects of seeding after the mechanical mastication treatment on the soil seed bank?

Methods

Site Description

The study site, Shay Mesa (37°58’42.97” N, 109°31’52.68” W), is located just outside the southwest corner of Canyonlands National Park – Needles District, at an elevation of 2,237 m. The spatial framework used for determining the landscape stratification of the study was the United States Department of Agriculture – Natural Resources Conservation Services (USDA-NRCS) ecological site system. An ecological site is defined as “a kind of land with specific physical characteristics which differs from other kinds of land in its ability to produce distinctive kinds and amounts of vegetation and in its response to management” (NRCS). Shay Mesa is an upland shallow loam pinyon-juniper ecological site with very-shallow to shallow soils (4 to 20 inches) (NRCS). The mean annual precipitation is 12 to 16 inches, approximately 60-70% of which comes from rain during the months March through October (NRCS). The driest months on average are April, May, and June; while August, September, and October are the wettest (NRCS). The plant community in the ecological site is generally comprised of grasses (15-25%), forbs (5-10%), shrubs (40-50%), and trees (20-30%) (NRCS).

Treatments

Land managers from the Bureau of Land Management (BLM) used three different fuel load reduction techniques to thin the P-J woodlands, which differ in both the type and severity of soil disturbance. The three treatments applied to Shay Mesa were mechanical mastication (mastication), hand pile and burn (pile burn), and lop and scatter followed by a broadcast burn (broadcast burn). Also, there was an untreated control adjacent to the treated sites. The treatment plots were to be divided into two sections, one of which was seeded with a predetermined seed mix comprised of 12 different species including grasses, forbs, and a few shrubs (Table 1). However, due to an error made by the BLM, only the control and the mastication plots received this treatment; the pile burn and broadcast burn plots were completely seeded, leaving no unseeded portions.

The mechanical mastication treatment is a practice wherein trees are mulched by a Tigercat feller buncher with an attached Fecon brush cutter to thin the tree canopy. In the fall season prior to the treatment, the mastication site was aerially seeded and then the mulch from the treatment was heterogeneously spread across the landscape. The mastication treatment area was approximately 0.75 km^2. Treatment occurred in September 2009. In the pile burn treatment, trees were cut and placed in 2 x 2 m paraboloid shaped piles that were spaced approximately 2 m apart in July 2009. The piles were left to dry and subsequently burned in October 2009. The pile burn treatment burned approximately 30-40% of the site. In the broadcast burn treatment, trees were cut and scattered evenly across the landscape and then burned by field crews. Trees for this treatment were cut and left to dry in July 2009 and burned in October 2009. After the prescribed burns, the pile burn and broadcast burn sites were hand seeded by all-terrain vehicles.

Seed Bank Study

Seed bank samples were collected from the control and treatment sites in June 2009. A 5 x 5 cm metal frame was pounded 5 cm into the ground using a rubber mallet. Then, using a trowel, soil was removed and placed into manila envelopes. Only the first 5 cm of the soil was collected because the majority of seeds occur at or above this depth (Roberts 1981). The samples were collected along the ten 35-m transects within each treatment (mastication, broadcast burn, and pile burn).

Samples were taken at different microsites: at each transect, including interspace; below a shrub canopy; and below a tree canopy (Table 2). In the pile burn, a fourth sample was collected from within a burn scar, and in the mastication treatment, a fourth sample was also collected from below a mulch pile (Table 2). In the broadcast burn treatment, nearly all of the interspace was exposed to fire and burned. When sampling occurred, burn scars we no longer visible making it difficult to determine if an area had previously burned. To avoid complication in the sampling scheme, areas between vegetation islands were treated as interspace for the broadcast burn, even though many of those soils were burned during the treatment.

For the different treatments, samples were collected near established vegetation transects. In order to reduce foot traffic and soil disturbance along the vegetation transects, seed bank samples were collected 5 m from the end of a transect in the opposite direction of the transect line. When sampling below the shrub canopy and tree canopy, the sample was collected 20 cm from the base of the plant. After the samples were collected, they were placed in manila envelopes and air-dried on site. Samples were then transferred back to the laboratory and stored in a dark, dry room to prevent germination for two months.

Greenhouse Study

To determine what species were present in the seed bank, each sample was placed in a 10 x 10 cm plastic tray and then placed under optimal temperature and moisture conditions in a greenhouse (Gross 1990). The soil sample was evenly spread to an approximate thickness of 0.8 cm over finely grated silica sand with a depth of 4 cm. Once all the samples were potted, they were watered every day or as needed to keep the soil moist. After two weeks in the greenhouse, dilute fertilizer was added with a NPK value of 20/20/20, 20% Nitrogen (N), 20% Phosphorus

Pentoxide (P_2O_5), and 20% Di-Potassium Oxide (K_2O), to all the samples to stimulate emergence and growth of the seedlings. Once each plant had reached a point where it could be identified, it was removed from the soil to allow other possible seedlings to germinate and reduce any competition. To confirm the identification of seedlings, three replicates of each seedling were transplanted into a mix of sand and potting soil, allowing for easier and clearer identification at the flowering stage.

Microsite Cover

Line-point intercept (LPI) method, as described in Herrick et al. (2005), was used in the field to estimate percent cover of microsites along each of the ten permanent transects. Along each transect, a pin was dropped perpendicular to the transect line every 0.5 m. Hits were recorded on a single pin every 0.5 m, for a total of 70 data points per 35 m transect (700 per site). Hits that fell into the following categories of grass, forb, shrub, tree, mulch, or interspace were used in the analysis.

Data Analysis

Seeding densities were calculated by counting the number of emerged seedlings within a sample and then dividing by .01, the area of the flat, converting seedling density to a m^2 area. The percent understory cover of each microsite was then multiplied by this value. By multiplying the original seedling densities by the percent cover of the particular microsite, the data was adjusted to better represent seedling densities within each treatment. The percent cover of each microsite was determined from LPI data collected for each individual transect. The adjusted seedling densities were then analyzed with respect to each treatment.

To identify the effects of different treatments on diversity, the Shannon-Wiener Index (S-W Index) was calculated for each microsite within a treatment. S-W Index measures both species richness and eveness. To calculate the S-W Index, the following equation was used:

$$\text{S-W Index} = \Sigma\, [P_i \ln(P_i)] \times (-1)$$

A one-way ANOVA was then used to test the effects of treatment with an accompanying post-hoc test (Tukey-Kramer test) on seedling density and species diversity. A two-way ANOVA with an accompanying post-hoc test (Tukey-Kramer Test) was used to test the effect of mastication and seeding on seedling density and species diversity.

The Jaccard index was used to determine the similarity between plant species in the field and seeds that germinated in the greenhouse experiment. The Jaccard index was calculated using the following equation:

$$\text{Jaccard} = a / (a + b + c)$$

Where (a) is the number of species found in both the seed bank data and the line-point data, (b) is the number of species found only in the seed bank data, and (c) is the number of species found only in the LPI data from the field.

Results

Species Representation

A total of 16 different species were recorded over the course of the greenhouse experiment. Life forms with the most recorded individuals were perennial forb (five species), annual forb (four species), perennial grass (three species), one shrub species, one exotic annual grass species and two unknown forbs (Table 3). The five most frequently recorded species in the seed bank study were *Lomatium* spp., *Draba cuneifolia*, *Cryptantha tenuis, Achnatherum hymenoides*, and *Bouteloua gracilis* (Table 3).

Few exotic species germinated in the seed bank study. Most importantly, *Bromus tectorum* (cheatgrass) was present at low levels (Figure 1). Furthermore, there were only 13 exotic seedlings in all of the samples combined (Table 3). Using Jaccard's Similarity Index to compare the species observed in the greenhouse to the field understory plant community, no similarity was found between the two (Table 4).

Treatment Effects on Seedling Densities and Diversity

As tested in a one-way ANOVA, treatment significantly affected seedling densities (F = 2.98, P = 0.04). More specifically, the pile burn treatment had a significantly higher seedling density than the broadcast burn treatment (Figure 2, P = 0.04). Species diversity was also significantly affected by treatment (F = 7.01, P = 0.0002). Moreover, species diversity was higher in the pile burn compared to the control and mastication (Figure 3, P = 0.0004, P = 0.002). Furthermore, there were no significant differences (P > 0.05) between species diversity values in the understory plant community assessed in the field compared to the seed bank study in all seeded treatments.

Effects of Seeding after Mastication on Seedling Densities and Diversity

Only three of the 12 species from the BLM seed mix were represented in the seed bank (Table 1 and Table 3). Moreover, seeding had no significant effect on seedling densities in the control and mastication treatment ($P > 0.05$). However, seeding did have a significant effect ($F = 16.42$, $P < 0.0001$) on species diversity—unseeded plots had higher diversity relative to seeded plots. Also, species diversity in the seeded control treatment was significantly higher ($P = 0.001$) for the field understory plant community compared to the seed bank study, while in all other comparisons there were no significant differences ($P > 0.05$).

Discussion

Treatment Effects on Seedling Densities

Although none of the treatments tested here altered seedling densities relative to the control, seedling densities were higher in the plots subjected to pile burn compared to broadcast burn. This may be a result of the placement of wood from thinning into distinct piles in the pile burn treatment. Seeds were then able to remain unexposed to fire in the interspaces between the piles. However, this was not the case in the broadcast burn, where the vast majority of the site was burned. Fire may be damaging to the soil seed bank as a result of the top layer of soil getting burned, destroying any seeds present (Armour et al. 1984). These results are similar to a previous study that observed an inverse relationship between seedling density and total area burned (Allen et al. 2008).

Moreover, the higher seedling densities could be due to the pile burn treatment causing less soil disturbance compared to the other treatments (Allen et al. 2008). The broadcast burn and mastication treatments are severe as they impact a larger portion of the treated area, thus preventing the survival of many seeds and causing a lower seedling density than the milder pile burn treatment. Another driver of the high seedling density in the pile burn treatment was that seedling density in the interspace microsite was at least two times higher relative to the other treatments (Figure 4).

Treatment Effects on Species Diversity and Exotics

Species diversity, like seedling density, appears to be affected by the pile burn treatment, while the other treatments had no statistical effect. Canopy openings and changes in soil resources following treatments, such as an increase of inorganic nitrogen, could allow rapid establishing plants like the perennial forb *Lomatium* spp. and the annual forb *Draba cuneifolia* to move in, increasing species diversity relative to the control (Allen et al. 2008; Everett and Ward 1984; USDA). What is driving this trend in the S-W index is a change in species richness as there is less representation of the perennial forb *Cryptantha tenius* (canyon cryptantha) and the perennial grass *Achnatherum hymenoides* (Indian ricegrass) in the control compared to the pile burn. While in the mastication, the lower S-W index is due to a lack of evenness among the plants present in the samples, as there is less abundance of canyon cryptantha and Indian ricegrass in the mastication compared to the pile burn.

However, species diversity in all treatments was comparatively low. The S-W index is typically on a scale of 0-6, scores below 1.5 indicate low species diversity and scores above 3 indicate high species diversity. Only the pile burn generated an index above 0.5, which is still a low diversity score.

Finally, exotic species, most importantly cheatgrass, did not have a significant presence in the local seed bank in any of the treatments (Figure 1). This is unusual as exotic species are typically opportunistic species that form large seed banks and establish quickly after fire treatment (Hulbert 1955). A possible explanation for the low germination of cheatgrass is that seed bank samples were not artificially vernalized prior to the greenhouse experiment (Hubert 1955). Vernalization, a prolonged exposure to cold conditions, is needed to promote germination of cheatgrass (Hulbert 1955). However, as seeds bank samples were collected in May, it was assumed that seeds had already gone through vernalization during the previous winter, thus eliminating the need for artificial vernalization (Allen et al. 2008).

Effects of Seeding after Treatment on Seedling Densities and Diversity

Seeding does not appear to have an effect on seedling densities. This seems counterintuitive; however, this trend could possibly be due to the quick-establishing plants from the artificial seeding already germinating before the collection of seed bank samples, thus leaving the soil seed bank in both seeded and unseeded plots statistically similar.

However, species diversity does appear to be affected by seeding as unseeded plots had higher diversity than seeded plots. A possible explanation could be that one of the seeded species had an overwhelming establishment in the seeded plots, thus out-competing other plants for space. An example of one plant out-competing the majority of other plants was found in a study examining vegetation's post-fire response after seeding, where a significant reduction in species diversity was observed (Schoennagel and Waller 1999). An overwhelming establishment of one of the seeded wheat grass species, *Triticum aestivum*, drove this trend (Schoennagel and Waller 1999). However, an overwhelming establishment of one seeded species was not the case in my study, as seeded plants did not have a higher representation in the seeded plots than non-seeded plants. In fact, all species identified had a higher representation in the unseeded plots. What is driving the trend in the data is a change in richness as the seeded control has less representation of the canyon cryptantha and Indian ricegrass compared to the unseeded version. While in the seeded mastication, species richness is similar to the unseeded version, instead, evenness or less abundance of canyon cryptantha and Indian ricegrass is causing the drop in the S-W index.

Management Implications

Pile burn appears to have the greatest effect on the seed bank out of all the treatments studied, positively affecting both seedling densities and species diversity. Seeding also appears to affect species diversity, but it is not as clear as to why seeding would reduce species diversity in the soil seed bank. Overall, the present study suggests that seeding may have little positive effect on the soil seed bank. Land managers could save money by reducing seeding efforts and instead focus on how fuel reduction treatments are applied in order to reduce damage to the soil surface, thus possibly allowing for greater regeneration from the soil seed bank.

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Species			
Common Name	**Scientific Name**	**Life Form**	**Proportion of Seed Mix**
Indian Ricegrass	*Oryzopsis hymenoides*	Perennial Grass	17%
Western Wheatgrass	*Pascopyrum smithii*	Perennial Grass	12%
Sandberg's Bluegrass	*Poa secunda ssp. secunda*	Perennial Grass	20%
Needle and Thread	*Stipa comata*	Perennial Grass	4%
Crested Wheatgrass	*Agropyron cristatum*	Perennial Grass	8%
Cicer Milkvetch	*Astragalus cicer*	Perennial Forb	7%
Blue Flax	*Linum lewisii appar*	Perennial Forb	15%
Sainfoin	*Onobrychis viciaefolia*	Perennial Forb	2%
Yellow Sweetclover	*Melilotus officinalis*	Perennial Forb	< 1%
Bitterbrush	*Purshia tridentata*	Shrub	1%
Mountain Big Sagebrush	*Artemisia tridentata ssp. vaseyana*	Shrub	12%
Winterfat	*Krasheninnikovia lanata*	Shrub	0.02

Table 1. Seeding mix applied by the Bureau of Land Management before prescribed fuel reduction treatments

Microsite	Control	Mastication	Pile Burn	Broadcast Burn
Interspace	×	×	×	×
Shrub Canopy	×	×	×	×
Tree Canopy	×	×	×	×
Mulch		×		
Burned Area			×	

Table 2. Microsites that were sampled within a given treatment. An ‘x’ denotes samples were taken from that particular microsite.

Table 3. Number of individual seedlings, across all treatments, observed in the greenhouse study. Species are listed from highest representation to lowest in the native, exotic and unknown categories.

Species		
Native	**Life Form**	
Lomatium spp.	Perennial Forb	417
Draba cuneifolia (Wedgeleaf Draba)	Annual Forb	331
Cryptantha tenuis (Canyon Cryptantha)	Perennial Forb	76
Achnatherum hymenoides (Indian Ricegrass)	Perennial Grass	67
Bouteloua gracilis (Blue Grama)	Perennial Grass	40
Arabis spp.	Perennial Forb	28
Artemisia tridentata (Big Sagebrush)	Shrub	12
Euphorbia maculata (Spotted Spurge)	Annual Forb	11
Arabis perennans (Perennial Rockcress)	Perennial Forb	10
Cordylanthus wrightii (Wright's Bird's Beak)	Annual Forb	3
Hesperostipa comata (Needle and Thread)	Perennial Grass	3
Exotic		
Bromus tectorum (Cheatgrass)	Annual Grass	7
Trifolium repens (White Clover)	Perennial Forb	4
Lactuca serriola (Prickly Lettuce)	Annual Forb	2
Unknown		
Unknown 2	Forb	3
Unknown 1	Forb	1

Treatment	Jaccard Similarity Index
Control Unseeded	0
Control Seeded	0.01
Mastication Unseeded	0.01
Mastication Seeded	0
Broadcast Burn Seeded	0.01
Pile Burn Seeded	0.02

Table 4. Jaccard similarity index (calculates how similar two sample sets are to each other) comparing the seedlings present in the greenhouse experiment to the seedlings present on each corresponding field transect. Values are shown as percentages.

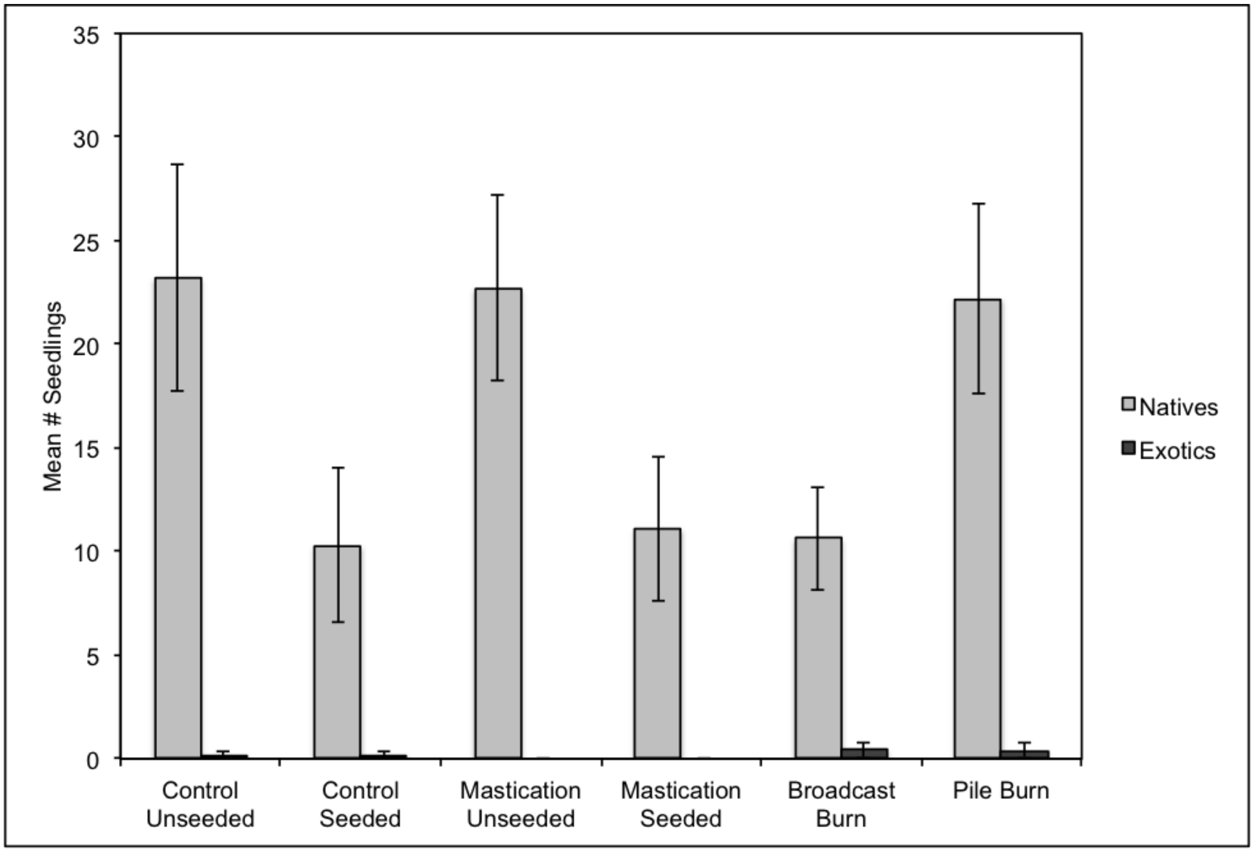

Figure 1. Number of seedlings (mean ± SE) in each treatment grouped into native species and exotic species.

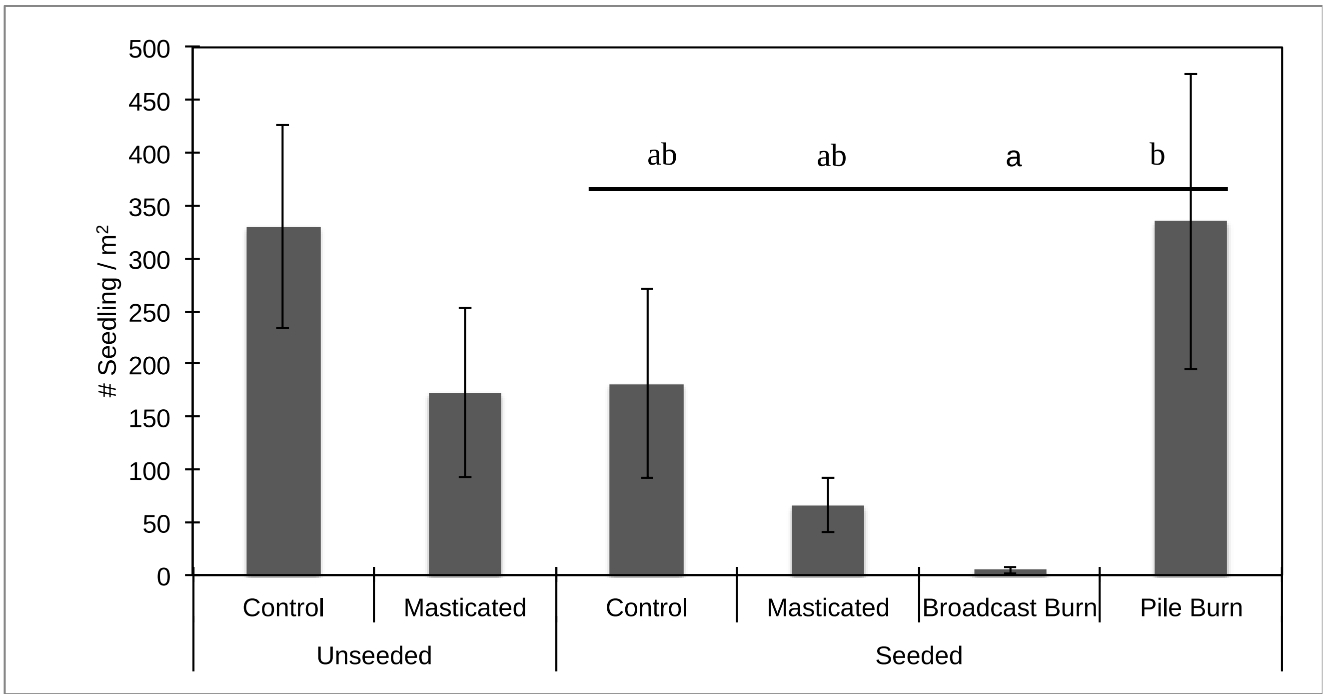

Figure 2. Seedling densities (# seedlings / m^2; mean ± SE) for seeded and unseeded treatments. Values are adjusted by the ratio determined by the percent cover of each microsite in the field. Different letters denote a significant difference ($P < 0.05$).

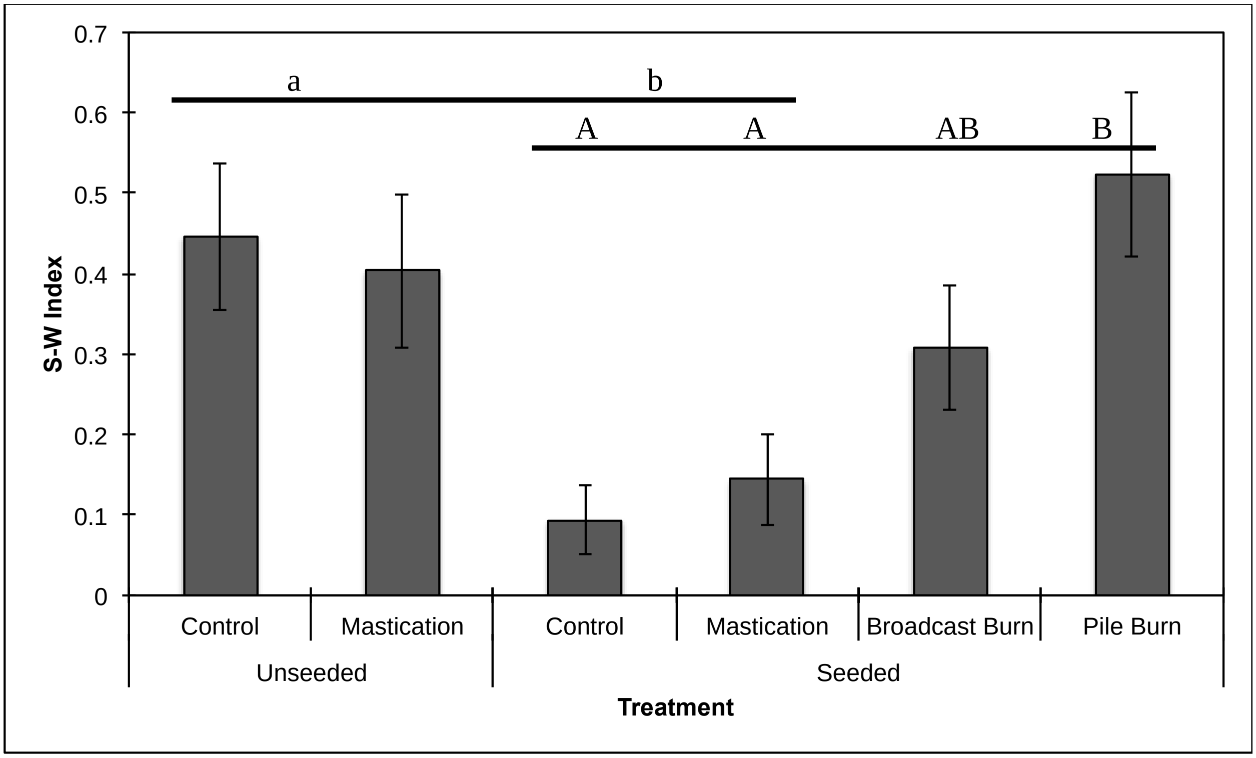

Figure 3. Species diversity (Mean Shannon-Wiener Index ± SE) for all seeded and unseeded treatments. Different letters denote a significant difference.

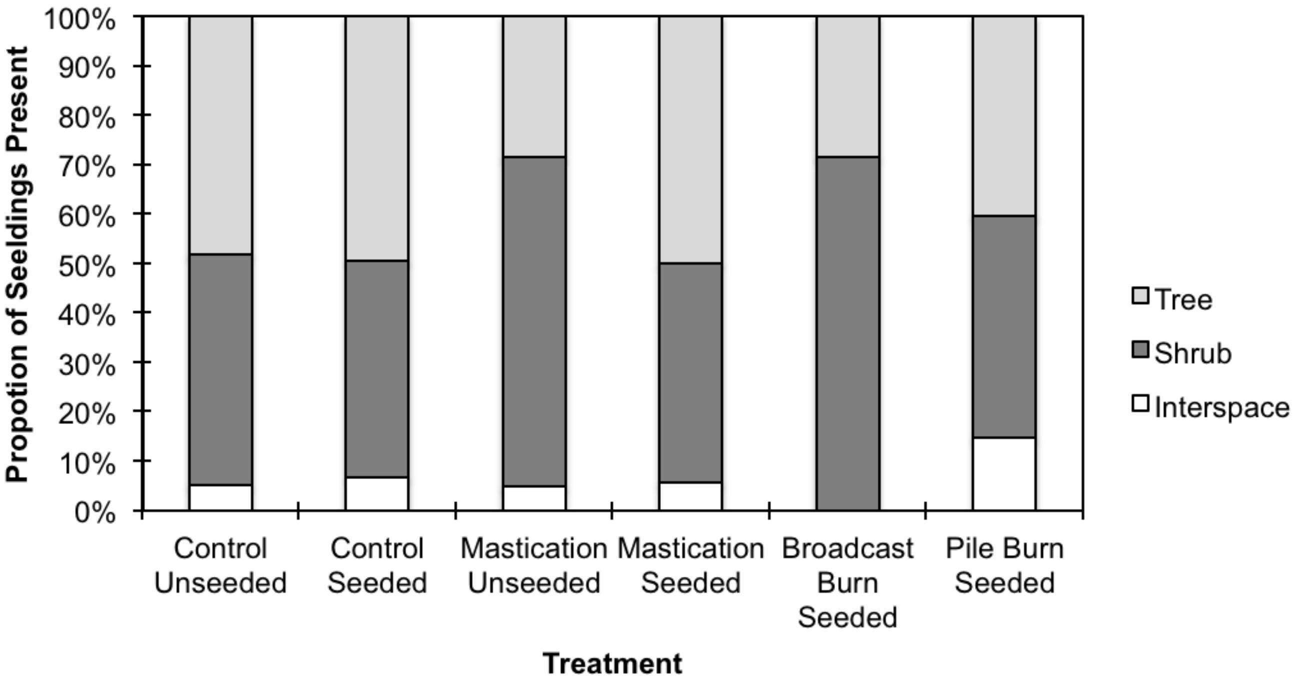

Figure 4. Proportion of seeds identified in each treatment based on which microsite they were collected from. Microsites include Tree (below a tree canopy), Shrub (below a shrub canopy), and Interspace (area between vegetation).