Response of Residual Native Species After Two-Way Chaining and Seeding in Utah

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Abstract—Pinyon-juniper woodlands have dramatically increased in both tree density and distribution over the last 150 years. This change led to depleted native herbaceous understory in pinyon-juniper woodlands. One method to increase herbaceous understory is to remove the trees and aerially seed. The objective of this study was to determine how variations of seed mixes used in past revegetation projects have affected residual native species.

Native herbaceous understory diversity and abundance were significantly greater in chained and seeded sites than in non-chained sites ($p \leq 0.02$ and $p \leq 0.05$ respectively), although diversity and abundance were low in both. Native herbaceous understory richness was similar between chained/seeded sites and non-chained pinyon-juniper sites. Seeding rates and mixtures showed low correlation with post-treatment native species diversity and abundance. The post treatment combined abundance of crested wheatgrass [*Agropyron cristatum* (L.) Gaertner] and intermediate wheatgrass [*Elymus hispidus* (Opiz.) Meld.] was negatively associated with native herbaceous understory diversity after two-way chaining and seeding with exotic species ($r^2 = 0.76$).

Future revegetation projects, on sites similar to those in central and southern Utah, should include a more site-specific approach to increasing native herbaceous understory diversity or abundance than the broad approach previously used in the revegetation efforts examined here. If increasing native species diversity or abundance are objectives in future revegetation projects, inclusion of adapted native species in conjunction with decreasing the proportion of exotic species in seed mixtures may be required.

Introduction

Pinyon-juniper [*Pinus edulis* Engelm. and *Juniperus osteosperma* (Torr.) Little] woodlands cover approximately 18 million hectares throughout the Intermountain West and approximately 6 million hectares in Utah (West 1984; O'Brien and Woudenberg 1999). Over the last 150 years pinyon-juniper woodlands have dramatically changed in tree density (from an open savanna type with scattered trees to a closed canopy community) and distribution (movement of woodlands into lower and higher elevations) (Tausch 1999; West 1999).

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The principal factors believed to contribute to the changes in tree density and distribution of pinyon-juniper woodlands include: (1) heavy livestock grazing following European settlement (West 1984), (2) an increase in fire suppression and corresponding decrease in fire frequency (West 1984; Bunting 1994), (3) a change in climate with rising mean annual temperatures (Ghil and Vautgard 1991), (4) cessation of the hunting, gathering and burning by populations of indigenous people that occurred during the Little Ice Age (Creque 1996; Tausch 1999), and (5) increasing atmospheric CO_2 levels that change community competitive interactions in favor of dominance by large woody perennials (Polley and others 1996; Farquhar 1997).

As pinyon-juniper woodlands become more dense and spread into adjacent sagebrush-grass plant communities, interspecific competition between trees and the understory species increase. Pinyon and juniper trees influence understory plants in several ways: by shading, sub-canopy litter accumulation and by the competition for soil moisture through the development of an extensive and competitive shallow root system (Schott and Pieper 1985). As mature trees obtain dominance, the remaining understory species are severely suppressed. Hurst (1975) and Dye and others (1995) report that understory suppression generally varies inversely with the tree overstory density. Additionally, Arnold and others (1964) found that as canopy cover increases, basal cover of grasses and forbs decrease.

Beginning in the early 1950s, earnest efforts were undertaken to improve the depleted pinyon-juniper ranges in the Western United States through mechanical removal of the pinyon-juniper overstory and replacement with a desirable shrub-herbaceous understory. Early efforts focused on increasing forage for livestock, while later objectives were expanded to include wildlife habitat restoration and watershed protection (Fairchild 1999; Roundy 1996). Early improvement techniques included: anchor chaining, cabling, hula dozing, bulldozing, windrowing and burning, and chemical treatments. After extensive research, two-way anchor chaining was most commonly employed because it was cost efficient, effectively reduced pinyon-juniper tree densities (Aro 1971; Parker 1971; Phillips 1977; Stevens 1999) and prepared an excellent seedbed (Plummer and others 1968; Stevens 1999). Two-way chaining entails dragging an anchor chain between two tractor crawlers one direction, aerially seeding, and then back chaining in the opposite direction to cover the seed and increase pinyon and juniper tree mortality (Plummer and others 1968; Aro 1975; Stevens and others 1975; Stevens 1999).

Due to understory suppression, pinyon-juniper woodlands usually lack sufficient seed of grass, forb and browse species for natural recovery of the community after treatment. To establish desired vegetation cover, seeds of desired species are often sown during treatment. Many successful revegetation projects in the Western United States resulted in replacement of degraded plant communities with substitutes containing mostly exotic species.

Requirements for establishing native species from seed in a rangeland setting were not fully understood in these early revegetation efforts. Native species showed poor establishment, seed availability was low and the seed that was available was relatively expensive (Pyke 1995). Additional factors prohibiting native species from being included in seed mixes were the inability of native plants to compete with exotic weeds such as cheatgrass [*Bromus tectorum* L.] and the susceptibility of native species to grazing (Anderson and Marlette 1986; Roundy and Call 1988; Chambers and Norton 1993). Extensive research was initiated on the establishment requirements of native plants, as well as several species from Europe, Russia and Asia (Plummer and others 1968; Kilcher 1969; Monsen 1975). Through this research, many exotic species demonstrated a better ability than native species to successfully establish and persist under arid conditions following chaining and seeding pinyon-juniper woodlands.

As a result of the success of selected exotic grasses, large tracts of treated pinyon-juniper woodland were seeded; generally with only a few exotic grass species dominating seed mixtures. Species diversity following treatment was not as much of a concern as the establishment of some type of vegetation, whether native or exotic (Pyke 1995). Two grasses in particular, crested wheatgrass [*Agropyron cristatum* L.] and intermediate wheatgrass [*Elymus hispidus* (Opiz) Meld], were used extensively for seeding rangelands throughout the Western United States because they were easily established and seed was readily available at low cost. Additionally, with the aggressive habits of these grasses, land managers felt they had found a tool to control weeds, reduce soil erosion and maintain or increase grazing capacities.

Plummer and others (1968) recognized several advantages for rangeland seedings to contain diverse seed mixtures rather than single species for several reasons. First, many of the areas that are seeded have varying terrain, micro-surface reliefs and climatic conditions. A diverse seed mixture will allow adapted species to excel and persist in different niches within the treated site. Second, a variety of forage species can extend the season of use for both livestock and wildlife. Third, a diverse community provides better overall ground cover than single species stands. Fourth, higher species diversity makes the community more resilient and shortens recovery time from long term disturbance. Although the aforementioned recommendations were made with respect to seed mixes in the late 1960s, few Federal land managers prescribed diverse seed mixes in chaining treatments until the mid to late 1980s.

Pyke and Archer (1991) asserted that competitive relationships of species used in rangelands need to be identified to determine if species can coexist and thereby facilitate greater species diversity on the site. Furthermore, a diversity of species and growth forms would provide more stable cover and more dependable productivity than a monoculture, because most sites are characterized by environmental variability. Pyke (1995) points out that even though competitive exotic species may be effective in suppressing weedy species, this same aggressive value may exclude desirable native species as well. Compatibility and competitive relationships among plants in mixtures appear to be rarely considered and research providing quantitative evidence is lacking.

Our objectives in this study were to determine whether native species diversity, richness and abundance differ between two-way chained and seeded plots and adjacent non-chained pinyon-juniper woodlands in Utah. Secondly, are there variables that can predict or explain these differences?

Methods

Study Sites

Ten sites were chosen for study throughout central and southern Utah that represent typical pinyon-juniper chainings. Study sites were located on state and Federal lands where the treatments had been conducted by Bureau of Land Management, U.S. Forest Service and/or Utah Division of Wildlife Resources personnel. Seed mixtures varied across sites with respect to seeding rate, number of species/mix and the proportions of individual species within each mix.

Chained sites ranged in age from 10 to 21 years since treatment. Non-chained sites are best characterized as climax pinyon-juniper woodlands with high canopy cover and sparse herbaceous understory. A few scattered shrubs were present and dominant overstory species were pinyon pine and Utah juniper. Chained sites contained mostly exotic grasses with the majority of sites exhibiting some re-encroachment of pinyon-juniper trees. Trees that were uprooted in the chaining treatment had been left on the ground as litter. Plant composition on chained sites included some native species that were present in the non-chained woodlands as well as exotic species that were seeded as part of the two-way chaining and seeding treatments.

A pair of study plots were established at each site. One of the paired plots was placed in pinyon-juniper woodland that had been two-way chained and aerially seeded between chaining passes with exotic grasses and forbs. The second of the paired plots was placed in adjacent non-chained pinyon-juniper woodland. To reduce any confounding effects due to placement of study plots, specific criteria for elevation, aspect and slope were used. The range of acceptable values for these variables were: (1) slopes below 20 percent, (2) aspects of south or west exposure, and (3) elevations from 1,800 to 2,400 m.

Only native grass and forb species (hereafter referred to as native herbaceous understory) were considered for native diversity, richness and abundance. Native shrubs were often included in seed mixtures, and inclusion of these shrubs in data analysis would confound interpretations about natural occurrences. Soil samples were collected at each site and analyzed for physical and chemical properties at Brigham Young University's Soil and Plant Analysis Laboratory. Although soil texture at the study sites varied, the majority had soil texture characterized as sandy loam or sandy clay loam.

Data Collection

Vegetation at each site was sampled along a 150 m transect. A 1 m^2 quadrat was placed on alternating sides of the transect, beginning on the left at the zero meter mark, and continuing at each 3 m interval for a total of 50 quadrats per transect. Percent cover of vegetation and cryptogamic crusts were estimated within each quadrat using a modified Daubenmire cover class method (Daubenmire 1959; Bailey and Poulton 1968). Nested frequency was determined for each species and cover type following Smith and others (1986, 1987). Nested frequency value were summed for each species over all quadrats (50) to get a total value for the site (a maximum value of 250).

Density of pinyon and juniper trees at 30 m intervals along each transect sites was estimated using the point-centered quarter method (Cottam and Curtis 1956). Canopy cover of pinyon and juniper trees was measured along each transect using the line-intercept method (Canfield 1941). Cover and nested frequency data for non-vegetation variables were also collected using the methods previously described. Non-vegetation variables include: litter, bare ground, rock and pavement.

Species richness (S) was defined as the total number of species encountered at a site. The Shannon-Weiner index was used to determine species diversity (S´) because it is more sensitive to the abundance of rare species (Peet 1974). S´ is the number of species of equal abundance in a community and equates to the antilog of H´ ($\sum(p_i)(\log_2 p_i)$), which is often used as the index of species diversity when using the Shannon-Weiner index (Krebs 1999).

Analysis

Differences in native herbaceous understory abundance, richness and the percent change in diversity between treated and native sites were tested using paired t-tests. The percent change in native species diversity was used so that relative comparisons could be made across all sites. Additionally, differences in individual native species abundance between chained and non-chained sites were also examined.

Regression analysis was used to develop predictive models for post-treatment changes in native species diversity and abundance. In the models, percent change in native species diversity and abundance between chained and non-chained woodlands were used as response variables. Time since chaining is a continuum and was used as a predictor variable to examine how time after treatment affects diversity and abundance across sites. Similarly, seeding rates are a continuum and were used as predictor variables to examine the effect of different seeding rates on native species diversity and abundance.

Several seed mix variables were examined including: total lbs/acre of seed, total number of seeds/m^2, total number of grass seeds/m^2, the proportion of the seed mix that was composed of crested and intermediate wheatgrasses seed (both individually and combined) and the individual and combined abundance of crested and intermediate wheatgrass after treatment.

Individual and combined abundance values for crested and intermediate wheatgrasses after treatment, as measured by sum of nested frequency, were used as predictor variables to examine possible post-treatment species effects. Pure live seed (PLS) information was unavailable for most sites. Therefore, data analysis concerning seed mixes was estimated using bulk seed rate information obtained from *Range Development and Improvements* (Vallentine 1989).

Results

Vegetation

Herbaceous understory cover was significantly greater (p = <0.001) for the chained sites than for the non-chained sites. Mean cover values were 18.9 percent and 1.9 percent respectively. Native herbaceous cover was different (p = 0.192), with 1.9 percent cover on the non-chained sites and 4.6 percent cover on the chained sites. Seeded grasses were not encountered on the non-chained sites.

Abundance, Diversity, and Richness

Native herbaceous understory abundance was significantly greater (p = 0.054) in the non-chained sites as compared to chained sites (fig. 1). Non-chained sites had 1.5 times greater sum of nested frequency values than chained sites. Native herbaceous understory richness was similar (p = 0.570) in the chained and non-chained sites averaging 11.4 species and 10.5 species respectively (fig. 2). Native herbaceous understory Shannon-Weiner diversity values were significantly greater (p = 0.022) in the non-chained than in chained sites (fig. 3). Non-chained sites had mean Shannon-Weiner diversity values nearly 2 times greater than the chained sites. Differences in individual species abundance were examined across all sites, however, individual native species were not encountered frequently enough to allow for statistical analysis.

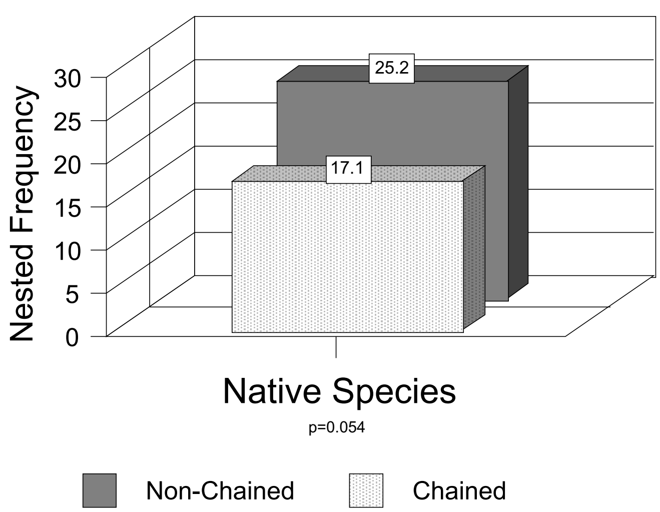

Figure 1—Native herbaceous understory species abundance.

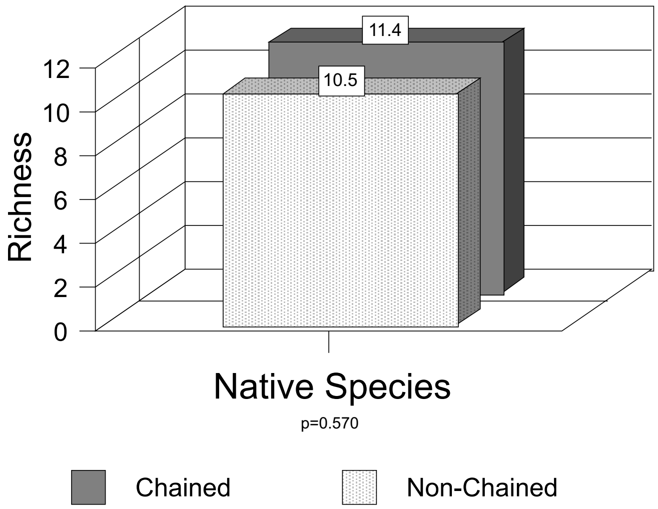

Figure 2—Native herbaceous understory species richness.

Time Since Treatment

Regression analysis was completed for time since treatment with native herbaceous understory diversity and native herbaceous understory abundance as response variables. Low correlation between native herbaceous understory abundance or diversity and time since treatment indicated no significant differences.

Seed Mixtures and Post-Treatment Abundance

Regression analysis was completed for several seed mixture variables, the abundance of crested and intermediate wheatgrasses after treatment as predictor variables with native herbaceous understory abundance and diversity as response variables (table 1). Native herbaceous understory abundance was negatively associated with the proportion of crested wheatgrass in the seed mix with an r^2 value of 0.55. Additionally, abundance of crested wheatgrass after treatment was negatively associated with native herbaceous understory abundance with an r^2 value of 0.61.

All seed mix variables examined showed poor correlation with native herbaceous understory diversity after treatment. However, the combined abundance of crested and intermediate wheatgrass after treatment best predicted the percent change in native herbaceous understory diversity after treatment. The combined abundance is negatively associated with an r^2 value of 0.76 (table 2).

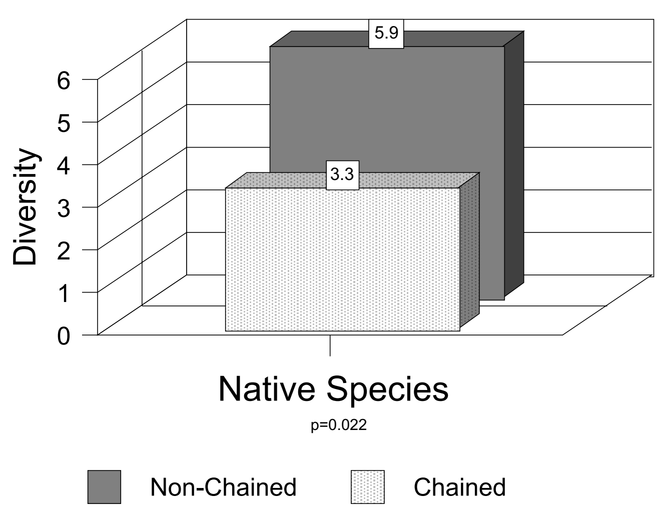

Figure 3—Native herbaceous understory species diversity.

Discussion

In this study, the non-chained sites had significantly greater native herbaceous understory diversity and abundance than the chained area. Although analysis indicated this was statistically significant, native herbaceous understory plants were rarely encountered and made up only a small portion of the cover in both the chained and non-chained woodland. The response of native species after two-way chaining and seeding pinyon-juniper sites can be influenced by several factors. These include: (1) plant density, condition and age of the plants left on the site following treatment, (2) competition from any seeded species, (3) grazing by wildlife and livestock, and (4) climatic conditions following treatment (Walker and others 1995). These influences could effect native herbaceous understory diversity and/or abundance after treatment.

Native species abundance, although significantly greater in the non-chained sites, was considered very low across all sites to begin with. Different factors can influence abundance of native species in both non-chained and chained sites, but residual effects of the pinyon and juniper trees may affect the native species in the chained area well after the treatment was completed. The subsequent community changes and the impact of competitive exotic species on desirable and undesirable species after treatment with crested and intermediate wheatgrass are generally well known and can provide insight about the results of our study.

Studies conducted by Heinrichs and Bolton (1950) in Saskatchewan lead them to conclude that crested wheatgrass was a strong competitor and eventually excluded some native species when seeded into areas of established introduced and native species. Hull and Klomp (1966) reported crested wheatgrass exhibited continued high production over a 33-year period. It persisted and even spread in some locations under adverse conditions. This included: heavy use, disease and extremes in temperature and moisture. Additionally, Hull and Stewart (1948) found crested wheatgrass to survive and spread into stands of cheatgrass.

Pavlychenko and Kirk (1946) conducted a study to determine if crested wheatgrass could control perennial weeds on dryland farms in Saskatchewan, Canada. Plots containing well established stands of perennial sow thistle [*Sonchus arvensis* L.], blue lettuce [*Lactuca tatarticas* L.], toad flax [*Linaria canadensis* (L.) Dum.-Cours.], Canada thistle

Table 1—Significance of seeding variables on native herbaceous understory abundance for chained pinyon-juniper woodlands in Utah.

Variable	F-value	Prob>F	r^2-value
Total seed lbs/acre	2.10	0.19	0.23
Total seed/m^2	3.25	0.11	0.29
Grass seed/m^{2*}	8.11	0.02	0.50
Proportion of crested wheatgrass in mix (seeds/m^2)*	9.71	0.01	0.55
Proportion of intermediate wheatgrass in mix (seeds/m^2)	1.18	0.31	0.13
Proportion of crested and intermediate wheatgrass in mix (seeds/m^2)*	8.00	0.02	0.50
Crested wheatgrass abundance after treatment*	12.63	0.01	0.61
Intermediate wheatgrass abundance after treatment*	0.14	0.72	0.02
Crested and Intermediate wheatgrass abundance after treatment*	5.07	0.05	0.39

* Negatively associated with response variable.

[*Cirsium arvense* (L.) Scop.], field bindweed [*Convolvulus arvense* L.], leafy spurge [*Euphorbia esula* L.], poverty weed [*Iva axillaris* L.], white top [*Cardaria draba* (L.) Desv.] and Russian knapweed [*Centaurea repens* L.] were hand seeded with crested wheatgrass at a rate of 28 kg/ha. After 5 years, all plants of perennial sow thistle, blue lettuce, toad flax and Canada thistle were eliminated from the plots. All other species were greatly reduced with field bindweed showing the least suppression. Crested wheatgrass was also recommended for seeding abandoned farmland occupied by Russian thistle [*Salsola iberica* A. Nels.] and tumble mustard [*Sisymbrium altissimum* L.] by Reitz and others (1936).

Intermediate wheatgrass has similar traits as crested wheatgrass with the exception that it is a sod former and is not as drought tolerant. It is able to compete very well with other species for resources and quickly established after seeding on treatments in Utah (Plummer and others 1970). Plummer and others (1970) also reported that a seed mixture containing crested wheatgrass, intermediate wheatgrass and Russian wildrye essentially eliminated cheatgrass on a site in Central Utah. Similarly, Skousen and others (1989) showed crested wheatgrass, intermediate wheatgrass and Russian wildrye to establish and persist over a long period of time in the Intermountain region.

Plant nutrients are essential for plant communities to establish and persist after treatment. Pinyon and juniper trees that have invaded a site and are now dominant in communities claim much of the water and nutrient resources that were previously used by the herbaceous species (Doughty 1987). Tiedemann (1987) reported that invasion of grass/forb and sagebrush/grass areas by pinyon and juniper was accompanied by a greater nutrient accumulation in

Table 2—Significance of seeding variables on percent change in native herbaceous species diversity (Shannon-Weiner Index) after treatment for chained pinyon-juniper woodlands in Utah.

Variable	F-value	Prob>F	r^2-value
Total seed lbs/acre	0.48	0.51	0.07
Total seed/m^{2*}	0.00	0.99	0.00
Grass seed/m^{2*}	1.08	0.33	0.12
Proportion of crested wheatgrass in mix (seeds/m^2)*	2.59	0.15	0.25
Proportion of intermediate wheatgrass in mix (seeds/m^2)*	0.96	0.36	0.11
Proportion of crested and intermediate wheatgrass in mix (seeds/m^2)*	2.50	0.15	0.24
Crested wheatgrass abundance after treatment*	4.62	0.06	0.37
Intermediate wheatgrass abundance after treatment*	6.77	0.03	0.46
Crested and Intermediate wheatgrass abundance after treatment*	25.56	0.00	0.76

* Negatively associated with response variable.

aboveground biomass. The native woodland sites investigated in this study were considered to be mature with a lack of herbaceous understory. Due to the lack of herbaceous understory species and the associated poor seed bank, seeds of exotic, perennial species were seeded during treatment to enhance the herbaceous vegetation component. Resources redistributed by removing the dominant pinyon-juniper overstory would be available for seedling establishment and plants that were present at the time of treatment. Exotic species may benefit more than natives species due to the shear abundance of exotic species seed on site. Furthermore, aggressive species, such as crested and intermediate wheatgrass, would have an even greater advantage due to less stringent germination requirements, more competitive seedlings and post-establishment competitiveness as compared to native species. Not surprisingly, seeded species abundance (sum of nested frequency) was significantly greater than native species abundance (66.5 and 17.1 respectively) after treatment on the sites examined in this study.

Another factor perhaps influencing the significant difference in diversity and abundance between chained and non-chained sites may be site potential changes imposed by the new assemblage of species on the treated sites. Several studies suggest that there may be long term negative impacts by crested wheatgrass stands on soil. Lesica and DeLuca (1999) provide a comprehensive review of literature regarding soil changes that can be attributed to crested wheatgrass stands in a mid-grass prairie. For instance, crested wheatgrass stands have a lower below ground biomass than the native prairie grasses (Dormaar and others 1995; Smoliak and Dormaar 1985). This can lead to lower energy input into the soil as compared to the native range and alter physical and biochemical processes (Dormaar and others 1978). Stands of crested wheatgrass are associated with higher bulk density, fewer water stable aggregates and lower levels of organic matter and nitrogen compared to stands of native grasses (Redente and others 1989; Dormaar and others 1978; Smoliak and others 1967). Crested wheatgrass also provides the soil with a relatively high concentration of carbohydrates and little organic nitrogen (Klein and others 1988). Klein and others (1988) suggest that these alterations to soil quality may prevent native species from invading crested wheatgrass monocultures. Mid-grass prairies obviously have different soil and site potentials, but it is worth pointing out the influences crested wheatgrass exhibits in some situations that were not examined in this specific situation. Similar soil chemical and physical changes may be occurring to soil in the Intermountain region after chaining and seeding with crested wheatgrass and may be restricting native species expansion or persistence.

Another influence listed by Walker and others (1995) affecting the recovery of residual native species following treatment is livestock and wildlife grazing. While livestock access and utilization of treated sites can be somewhat controlled, wildlife utilization, and its' measurement, is another matter.

Some variables that were presumed to influence native species response prior to this study ultimately showed low correlation. For instance, it was hypothesized that as time passed since chaining, native species would increase in density relative to when it was seeded. Our data indicate that this is not the case as seeded species values were similar for all sites regardless of time since treatment. Similarly, Walker and others (1995) reported that although native grass abundance responded positively for 3 years following chaining, the native grasses slowly started showing negative response and declined over time, presumably from competition with exotic grasses. They also report that 23 years after chaining and seeding, the exotic grasses became more dominant in the communities and that plant dominance had not yet stabilized.

Seed mixes used in the revegetation projects examined in this study varied with respect to total seeding rate and the proportion of various species such as crested and intermediate wheatgrass within the mixture across all sites. One objective of this study was to determine if variations of seed mixtures affected native species diversity and abundance. Data from this study indicated that both native species abundance and diversity were significantly lower in the chained plots versus the non-chained plots. However, these differences were best correlated with the abundance of crested and intermediate wheatgrass after chaining and seeding rather than the specific seed mixtures used on the sites. This raised the question whether a correlation exists between the seed mixes used on these sites and the resulting abundance of species following treatment. If a significant correlation existed, seed mixes might be tailored for improved native species response.

Regression analysis showed low association between proportions of species in the seed mixes and the relative abundance of crested and intermediate wheatgrass after treatment. These results are similar to those of Davis and Harper (1990). They reported that it is difficult to maintain a stand of specified composition after treatment because each species responds differently to natural and imposed environmental factors. Pyke (1995) also points out that although many species are included in a seed mix, establishment and persistence of each species depends on many biotic and abiotic factors. With this in mind, it should not be surprising that the assemblage of plants on a site would not necessarily correlate to the seed mix applied to the site and would vary through time in response to various external factors.

The judgement of success or failure of the treatments reviewed in this study should not be solely based on the diversity or abundance of native species following treatment. The goals and objectives for the revegetation projects examined in this study were generally to protect the soil resource, increase forage for livestock and/or restore big game ranges; not to enhance native species diversity or abundance. The approach used by these land managers was to get desirable plants, whether they be exotic or native, to establish under arid conditions following chaining pinyon-juniper woodlands. If increasing native species diversity or abundance is to be considered an objective in the future, this study indicates that a different approach than previously used should be taken on sites similar to those examined in this study.

Conclusions

Native species diversity and abundance were significantly lower after chaining and seeding. Varying combinations of introduced species in the seed mix showed some association with the resulting native herbaceous understory diversity and abundance. However, post-treatment abundance of crested and intermediate wheatgrass combined was the best indicator of native herbaceous understory diversity. This association was negative. Although this may lead one to believe that if the proportion of crested and intermediate wheatgrass were decreased in the seed mix, the abundance of these species after treatment would decrease as well. This was not the case as the proportion of crested and intermediate seeds in the seed mix had low correlation with crested and intermediate wheatgrass abundance at the point in time when these sites were sampled.

Inclusion of adapted native species in the seed mix in conjunction with decreased proportions of introduced species may be one alternative to enhance the native species community after treatment. This does not necessarily mean excluding exotic species from seed mixes entirely, but determining the correct balance of exotic and native species. Because site potential is potentially altered after pinyon-juniper invasion and the ensuing treatment, native species alone in a seed mix may be inadequate to satisfy desired goals or objectives, especially in light of the abundance of invasive annual and secondary perennial weeds spreading throughout the Intermountain West. Initially, protection of the site may be the prudent course of action with follow up treatments designed to increase native species diversity.

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