Seeding Versus Natural Regeneration: A Comparison of Vegetation Change Following Thinning and Burning in Ponderosa Pine

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Abstract—The decision whether to seed with native species following restoration treatments should be based on existing vegetation, species present in or absent from the soil seed bank, past management history, microclimate conditions and soils. We installed three permanent monitoring plots in two areas (total 18.6 ha) at Mt. Trumbull, AZ. Trees were thinned and the sites burned in 1996 and 1997. A 5 ha area was seeded with native shrub, grass and forb species; the remaining 13.6 ha were unseeded. Pretreatment species richness ranged from none to five species per plot. We recorded 13 graminoid and eight shrub species in the seeded area, and four graminoid and four shrub species in the unseeded area. The greatest increase in species richness in both seeded and unseeded plots occurred approximately 1.8 years posttreatment. Perennial native species dominated plant cover by 2.8 years, although annual native forbs dominate the soil seed bank. Perennial grasses are nearly absent from the seed bank. The seeded area had the highest diversity, but it also had twice as many nonnative species (14 versus 7 in the unseeded plots). By August 1999, maximum species richness reached 51 species on the seeded plot. Of these species, 80 percent were native. Although seeding increases diversity, it may also have the long-term tradeoff of introducing new genotypes and species, both native and nonnative.

Introduction

Human-induced changes that have impacted herbaceous forbs, grass and shrub species over approximately the last 150 years in Southwestern ponderosa pine forests have been attributed primarily to domestic livestock overgrazing, active fire suppression, increased ponderosa pine density, and climate changes (Arnold 1950; Weaver 1951; Cooper 1960; Covington and Moore 1994; Touchan and others 1995; Covington and others 1997). Attempts to restore the herbaceous and shrub species in Southwestern ponderosa pine forests are hampered by both ecological and social considerations. The scale of ecological restoration projects in the Southwest may be on the order of thousands of hectares. In addition to tree thinning and prescribed burning, restoration of these areas sometimes requires seeding large amounts of native seed. Seeding with native species poses many challenges: seed may be prohibitively expensive, unavailable in the quantities necessary, or collected from an area that is geographically or climatologically dissimilar to the area undergoing restoration. Even if these seeds are available and applied to a site, seed or seedling mortality may occur from competition (by both native and nonnative species), disease, herbivory, lack of mycorrhizal inoculants, inclement weather, or unfulfilled germination requirements or cues. Written historic records and photographs may be unavailable, further hampering efforts to define past plant communities and conditions. Other considerations are a lack of communication between and within government agencies and other organizations, past management practices (such as logging and road building), and a lack of understanding or interest by the general public. Some of these factors may be corrected or improved in order to establish vegetation on restored sites. Others cannot be overcome due to limited resources or permanent landscape changes and must be considered in order to achieve management goals for restoration.

Recent historic herbaceous and shrub species composition and abundance are largely unknown for Southwestern ponderosa pine forests, and thus restoration targets must be determined without the benefit of this information. Knowledge of historic herbaceous plant communities is limited due to a reduced capacity for preservation of nonwoody vegetation in the soil, and limited historical records. A variety of methods, techniques, and tools have been used to determine historical species composition and abundance. These methods and tools include historical records and photographs, packrat middens, palynology, relict sites (Kaufmann and others 1994), diaries, surveys, military expeditions (Dick-Peddie 1993) and opal phytoliths (Fisher and others 1995; Kerns 1999).

The main objective of this study was to compare a seeded and an unseeded area to collect material for further data exploration and generation of hypotheses. This information can then be used to make seeding decisions in areas of ponderosa pine forest undergoing ecological restoration.

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Study Area

The study area lies within the Grand Canyon–Parashant National Monument, in northwestern Arizona, between the Mt. Logan and Mt. Trumbull Wilderness areas and approximately 95 km southwest of Fredonia, AZ. The study area is of primarily the ponderosa pine forest type with intermingled patches of New Mexico locust (*Robinia neomexicana*), Gambel oak (*Quercus gambelii*), and big sagebrush (*Artemisia tridentata*). Precipitation occurs annually in a bimodal distribution pattern and annual precipitation varies between 38–64 cm (USDI BLM 1990). Fire scars collected from individual ponderosa pine trees indicate that fires occurred every 4 to 6 years prior to Euro-American settlement (Fulé 1997 and unpublished data).

The Southwestern Ecological Restoration Project is a cooperative study among the Bureau of Land Management, Northern Arizona University, and the Arizona Game and Fish Department. The area is managed by the BLM and encompasses approximately 18,500 ha. Specifically, the data for this study were collected in two units, one 5.3 ha in size, which was seeded with a mixture of native grasses, forbs, and shrubs. The other unit (13.4 ha) was not artificially seeded and relied on natural regeneration by propagules already onsite or dispersed onto the site by wind, water, animals, or some other mechanism. The objective of the seeding was to increase species richness and diversity and to decrease soil erosion following ecological restoration treatments of tree thinning and prescribed burning.

Methods and Materials

Modified National Park Service fire monitoring protocols (NPS 1992) were used for the plot installation and long-term vegetation monitoring across the entire 18,500 ha project area. The point line-intercept method was used for vegetation monitoring. We installed two 50 m transects per plot, and inventoried these lines every 30 cm for a total of 332 points per plot. Species that were not intercepted by the transects were recorded within a 5 m belt on either side of the transects (hereafter referred to as "belt transects"). Three of these monitoring plots fell within the immediate study area: one in the seeded unit and two in the unseeded unit. Although many more plots were established across the landscape over several years, only data from these three plots will be discussed in this paper due to the longer period over which these plots have been monitored and their use as "demonstration" plots.

We conducted pretreatment inventories in the fall of 1995 in the unit to be seeded and in the spring of 1996 in the unseeded unit. The area was thinned of postsettlement trees in the summer of 1996 and burned in the fall of 1996. The 5.3 ha unit was broadcast seeded in December of 1996 and reseeded the following year using a chain pulled behind an all terrain vehicle (ATV) to cover seed with soil. Both units were fenced to exclude cattle, but deer were able to access the area. The plots were reinventoried in August 1997, 1998 and 1999. Species that were seeded are listed in table 1. The cost of seeding was estimated to be approximately $214 per acre (1996 dollars), with additional money spent on reseeding in 1998 ($26 per acre). Seed was certified "weed free," but germination testing was not conducted by the authors.

Table 1—List of species seeded at Mt. Trumbull in 5 ha area.

Grasses	*Purshia tridentate*
Achnatherum hymenoides	*Rhus trilobata*
Bouteloua gracilis	*Ribes cereum*
Bromus marginatus	*Sambucus cerulea*
Elymus elymoides	*Symphoricarpos oreophilus*
Elymus trachycaulus	**Forbs**
Koeleria macrantha	*Eriogonum umbellatum*[a]
Pascopyrum smithii	*Linum lewisii*[a]
Schizachyrium scoparius	*Penstemon barbatus*
Shrubs	*Penstemon palmeri*
Mahonia repens	

[a]Species seeded in 1997, but not in 1996.

Nomenclature in this paper was adopted from the USDA Plants Database (2000), Utah Flora (Welsh and others 1993), and Intermountain Flora (Cronquist and others 1972, 1977, 1984, 1989, 1994 and 1997).

Results

Percent Ground Cover

Percentages of substrates and plant cover are shown in figure 1. Prior to ecological restoration treatments, 86 percent of the ground cover in the seeded unit consisted of litter (primarily pine needles), and plant cover was less than 1 percent. In the unseeded unit, litter averaged 47 percent prior to treatment and fell to 23 percent the year following ecological restoration treatments. By 1999 (the third year following treatments), litter had increased to 44 percent in this unit, while in the seeded unit, litter increased to 24 percent. Plant cover in the unseeded unit rose from 6 percent (pretreatment) to a high of 50 percent in 1998 due primarily to the occurrence of early successional annuals and short-lived perennials, such as lambsquarters (*Chenopodium* spp.), spreading groundsmoke (*Gayophytum diffusum*) and silver lupine (*Lupinus argenteus*). Plant cover leveled off in 1999 to 25 percent in this unit. However, in the seeded unit, plant cover continued to increase in 1999 to 44 percent. Soil cover dramatically increased in the seeded unit following treatments: 5 percent pretreatment and 58 percent in 1997. It has continued to decrease in both units as other types of cover begin to predominate.

Species Composition

The only two plant families represented in the seeded unit in 1997, the first year following restoration treatments, were the Chenopodiaceae (goosefoot family) and the Poaceae (grass family) (table 2). In 1998, 11 families were represented. The Chenopodiaceae family was most common (23 percent of the ground cover). There were 15 families in 1999. The most common families were the Scrophulariaceae, Asteraceae, and Chenopodiaceae.

The most numerous species in the seeded unit in 1997 were *Chenopodium leptophyllum* (narrowleaf goosefoot), *Agropyron* sp. (wheatgrass), *Bouteloua gracilis* (blue grama), and *Elymus elymoides* (squirreltail). By 1999, perennial

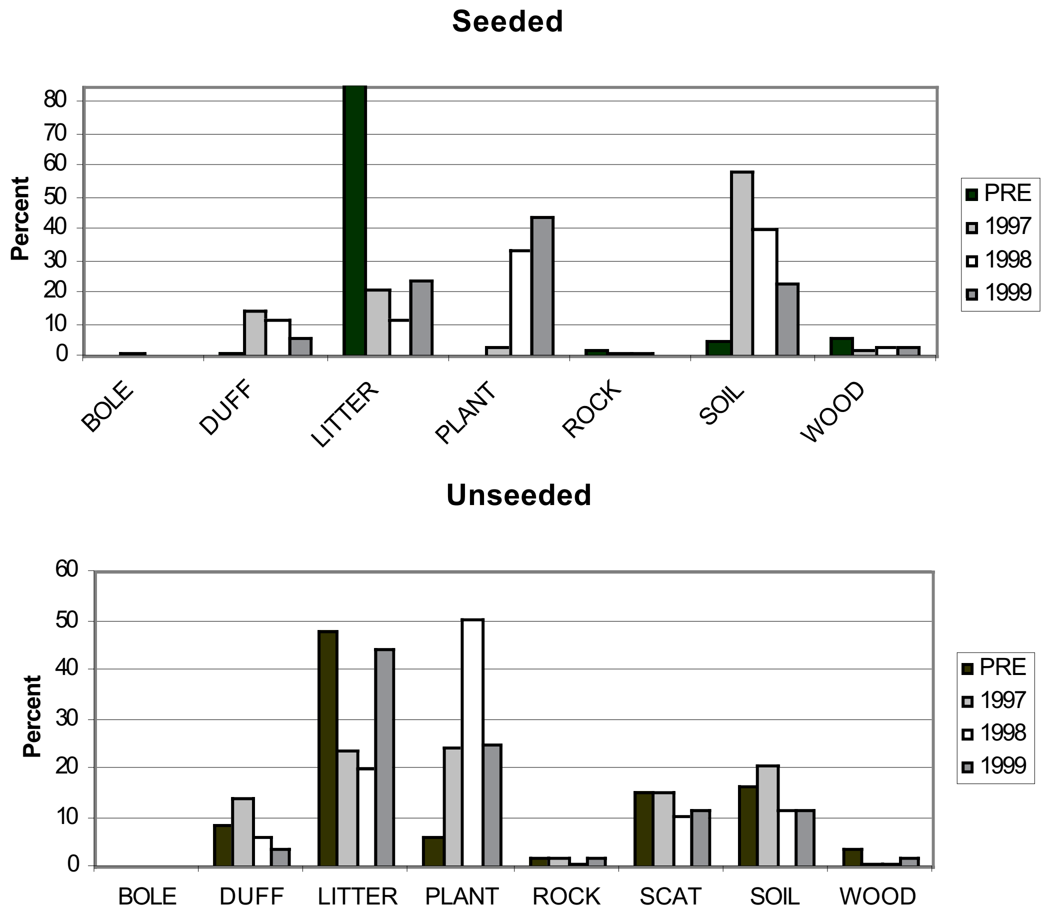

Figure 1—Percent ground cover of plants and substrates in the seeded and unseeded units at Mt. Trumbull.

grasses and forbs were beginning to dominate this site. The five most numerous species were *Agropyron (Pascopyrum) smithii* (western wheatgrass), *Bromus carinatus* (mountain brome), *Conyza canadensis* (Canadian horseweed), *Thinopyrum intermedium* (intermediate wheatgrass) and *Chenopodium album* (lambsquarters).

In the unseeded unit, pretreatment family representation was limited to Poaceae, Asteraceae, Fabaceae, and Scrophulariaceae (table 2). In 1997, there were eight families represented in this unit. The most common families were the Fabaceae, Asteraceae, Polygonaceae, Poaceae, and Scrophulariaceae. The number of families was highest in 1998 (11). The number of families decreased in 1999 to eight as some of the early-successional species began to disappear from the aboveground vegetation. Families included Poaceae, Asteraceae, Fabaceae, Onagraceae, Scrophulariaceae, Polygonaceae, Fagaceae and Chenopodiaceae.

The most numerous species in the unseeded unit in 1997 were *Artemisia tridentata* (big sagebrush), *Lupinus argenteus* (silver lupine), *Polygonum douglasii* (Johnston's knotweed), and *Elymus elymoides* (squirreltail). The most common species in 1999 were the same four with the addition of *Senecio multilobatus* (lobeleaf groundsel) and *Bromus tectorum* (cheatgrass).

In the seeded unit, the percent cover of annuals peaked in 1998, 2 years following restoration treatments, at approximately 29 percent of the ground cover. Perennials continued to increase and composed 31 percent of the ground cover in 1999. In the unseeded unit, both annuals and perennials peaked in 1998. Annuals composed 20 percent and perennials approximately 40 percent of the ground cover. By 1999, annuals had decreased to 7 percent and perennials to 20 percent of the ground cover. Biennials remained at less than 5 percent of the ground cover in all years and in both treatments.

Nonnative Species

The number of nonnative species was higher in the seeded unit. Eight species were intercepted by the transects: *Agropyron cristatum* (crested wheatgrass), *Bromus inermis* (smooth brome), *Bromus tectorum* (cheatgrass), *Lappula occidentalis* var. *occidentalis* (stickseed), *Marrubium vulgare* (horehound), *Salsola tragus* (Russian thistle), *Thinopyrum intermedium* (intermediate wheatgrass) and *Verbascum thapsus* (common mullein). In addition, *Bromus commutatus* (hairy chess), *Bromus japonicus* (Japanese brome), *Convolvulus arvensis* (field bindweed), *Lactuca serriola* (prickly

Table 2—Percent frequency of plant families over time in a seeded and an unseeded unit at Mt. Trumbull, AZ.

Unit and year	Plant families	Percent
Seeded unit		
Pretreatment	No species present	
1997	Chenopodiaceae	2.1
	Poaceae	1.5
1998	Chenopodiaceae	24
	Scrophulariaceae	3.0
	Onagraceae	2.7
	Polygonaceae	1.5
	Poaceae	1.5
	Fumiariaceae	0.9
	Boraginaceae	0.9
	Papaveraceae	0.6
	Lamiaceae	0.3
	Asteraceae	0.3
	Solanaceae	0.3
1999	Poaceae	25
	Scrophulariaceae	7.5
	Asteraceae	5.1
	Chenopodiaceae	4.8
	Boraginaceae	2.4
	Onagraceae	1.8
	Polygonaceae	1.5
	Lamiaceae	1.5
	Amaranthaceae	1.2
	Solanaceae	1.2
	Nyctaginaceae	0.6
	Verbenaceae	0.6
	Linaceae	0.3
	Fabaceae	0.3
	Brassicaceae	0.3
Unseeded unit		
Pretreatment	Poaceae	2.6
	Asteraceae	2.4
	Fabaceae	0.8
	Scrophulariaceae	0.5
1997	Fabaceae	10
	Asteraceae	5.1
	Poaceae	3.0
	Polygonaceae	2.3
	Scrophulariaceae	1.7
	Euphorbiaceae	0.6
	Chenopodiaceae	0.2
	Rhamnaceae	0.2
1998	Fabaceae	22
	Asteraceae	11
	Poaceae	6.9
	Onagraceae	6.9
	Scrophulariaceae	5.6
	Polygonaceae	4.8
	Chenopodiaceae	2.9
	Euphorbiaceae	1.2
	Fagaceae	1.1
	Polemoniaceae	0.5
	Brassicaceae	0.2
1999	Poaceae	9.9
	Asteraceae	8.7
	Fabaceae	5.0
	Onagraceae	1.7
	Polygonaceae	1.2
	Scrophulariaceae	1.1
	Fagaceae	0.5
	Chenopodiaceae	0.3

lettuce), *Poa pratensis* (Kentucky bluegrass) and *Tragopogon dubius* (salsify) were encountered within the 20 m wide belt transect. Percentages of native and nonnative species are given in table 3. There was an increasing trend of nonnatives in the seeded unit, from less than 1 percent of the vegetative cover in 1997 to approximately 24 percent of the vegetative cover in 1999. In the unseeded unit, nonnatives showed an increasing trend as well, from 5 percent in 1996 to 13 percent in 1999. Cheatgrass and field bindweed, both inventoried in this study, are listed in Arizona as noxious weeds

Only three nonnative species were captured by the transects in the unseeded unit: *B. tectorum* (cheatgrass), *L. serriola* (prickly lettuce) and *V. thapsus* (common mullein). Four additional species were inventoried in the belt transects: *Polygonum aviculare* (prostrate knotweed), *Polygonum convolvulus* (black bindweed), *P. pratensis* (Kentucky bluegrass), and *T. dubius* (salsify).

Reasons for the larger number of nonnatives in the seeded unit could be due to: (1) their presence in the soil seed bank; (2) as contaminants in the seed mix; (3) increased foot traffic in this unit because of its use as a demonstration site, however, the unseeded unit is also used for that purpose; or (4) through colonization from offsite by dispersal mechanisms. The seeded unit is in close proximity to a meadow.

Grasses

Ten species of grasses were inventoried in the seeded unit. These species were *Achnatherum hymenoides* (Indian ricegrass), *A. cristatum, Agropyron (Pascopyrum) smithii* (western wheatgrass), *Bouteloua gracilis* (blue grama), *Bromus carinatus* (mountain brome), *B. inermis, B. tectorum, Elymus elymoides* (squirreltail), *Koeleria cristatum* (junegrass), and *T. intermedium*. In addition, the belt transect contained *B. commutatus, B. japonicus,* and *P. pratensis*. *Schizachyrium scoparium* (little bluestem) was seeded, but was not recorded in the monitoring plots prior to 2000.

Only four species of grasses were present in the plots in the unseeded unit and thus most likely regenerated from the soil seed bank or were carried in from the area surrounding the site. These species were *Bouteloua gracilis, Bromus tectorum, Elymus elymoides*, and *Poa fendleriana*. *Poa pratensis* was also captured by the belt transect.

Table 3—Percentages of native and nonnative species in the seeded and unseeded units at Mt. Trumbull.

Plot	Year	Native	Nonnative	Unknown
		percent		
Seeded	1995	—	—	—
	1997	75	—	25
	1998	92	6	2
	1999	74	24	2
Unseeded	1996	86	15	—
	1997	95	5	—
	1998	92	9	—
	1999	87	13	—

Shrubs

Eight species of shrubs were present in the seeded unit. These species were *Amelanchier utahensis* (Utah serviceberry), *Arctostaphylos pungens* (pointleaf manzanita), *Garrya flavescens* (ashy silktassel), *Purshia tridentata* (antelope bitterbrush), *Rhus trilobata* (skunkbush sumac), *Ribes cereum* (wax currant), and *Symphoricarpos oreophilus* (whortleleaf snowberry). Bitterbrush, sumac, currant, and snowberry were seeded, so it is difficult to ascertain whether the species monitored on the plots came from natural regeneration or from seeding. However, seeding with shrub species appeared to be effective with the exception of *Mahonia repens* (Oregon-grape). No specimens of this taxa were found in the seeded unit. *Sambucus cerulea* (blue elderberry) was not captured by the monitoring plots, although it was observed nearby.

In the unseeded unit, four species were inventoried on the plots: *A. pungens, Artemisia tridentata, A. utahensis,* and *R. cereum*. Species that were observed in the unit, but not captured by the monitoring plots, included *G. flavescens, A. pungens* and *Ceanothus fendleri* (buckbrush). These species presumably sprouted after fire. With the exception of big sagebrush (*A. tridentata*), shrubs were not detected in the soil seed bank (or propagule bank) from samples taken at Mt. Trumbull (Springer 1999). However, some species apparently are still present in the form of underground rhizomes or buds and will regenerate following fire. Nearly all shrub species in these units were heavily browsed, most likely by deer or rabbits, since elk are not present at Mt. Trumbull and cattle were excluded from the study area (personal observations).

Legumes

No species of legumes (Fabaceae or pea family) were manually seeded in either unit and no species of legumes were captured by the line transects in the seeded unit. The only occurrence of legumes in this unit was one record of *Lotus utahensis* (Utah birdsfoot trefoil) from the belt transects in 1998.

In the unseeded unit, *Lupinus argenteus* (silver lupine) was recorded on the line transects prior to treatment. Silver lupine was recorded in all years in both plots in this unit. Its frequency was highest in 1998, the year following thinning and burning (an average of 16 percent of the ground cover). Other legumes recorded in the unseeded unit were *Lotus spp*. (*Lotus plebius, Lotus wrightii, Lotus* sp.) in 1997, 1998, and 1999 and *Lupinus kingii* (King's lupine) in 1998 on a belt transect.

Simpson's Index and Species Richness

Pretreatment species richness was very low (less than five species) on the line transects on all plots (fig. 2). In 1998, it peaked in the unseeded unit (17 species), but continued to increase in the seeded unit in 1999 (28 species). The total number of species in the seeded unit, including species captured on the belt transects, was 51. The average number of species per plot in the unseeded unit was 36. The Simpson's diversity index showed a similar trend to species richness in the seeded unit (fig. 3), increasing from 0 in the pretreatment inventory to 14 in 1999. In the unseeded unit, it peaked at 10 in one plot in 1998, but continued to increase slightly in the other plot through 1999 (fig. 3).

Discussion

Seeding is a complex issue, and the positive and negative aspects must be weighed before making any type of management decision relating to ecological restoration in Southwestern ponderosa pine forests. Seeding has many advantages including decreased soil erosion (Beyers and others 1998) and increased vegetative ground cover (Williamson 1984; Tyser and others 1998). It also produces an increase in the amount of available seed stock for colonizing nearby areas (Jacobson and others 1994) and, if successful, it will increase species richness and diversity (Grant and others 1997). However, seeding also has disadvantages, such as high cost and lack of locally-adapted genetic material for most areas (Dunne 1999; Roundy 1999). Also, increased species diversity can be a major disadvantage if this increase is due to nonnative species. This study, though exploratory, seems to indicate that although seeding increased the species richness and diversity, these increases were due in part to increases in nonnative species that were possibly brought onsite by the seed mixture. The percentage of nonnatives in the seeded unit continued to increase in 1999 and will be monitored to determine if this trend continues.

There is presently a dearth of native perennial grasses, legumes, and shrubs in the ponderosa pine forests of the Mt. Trumbull area, based on this study, on previous soil seed bank studies (Springer 1999), and on data from other areas of ponderosa pine forest in northern Arizona. Rasmussen (1941), in one of the few historical publications from the Arizona Strip containing information on species frequency, mentions that by the time of his publication, certain legumes had entirely disappeared from the Kaibab Plateau (about 45 km to the east) due in part to severe overgrazing by wild

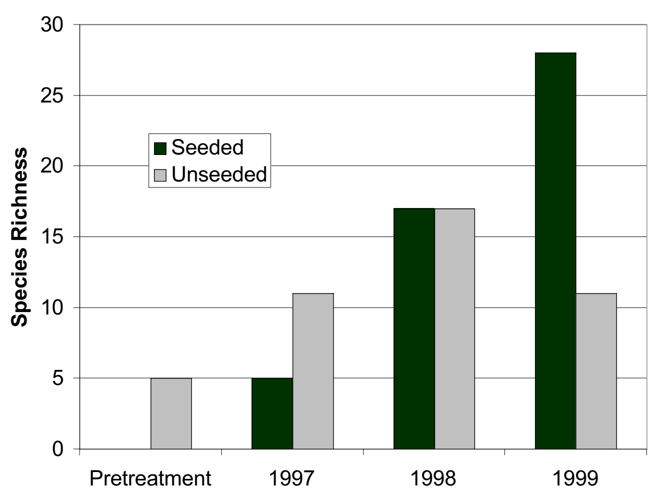

Figure 2—Species richness in the seeded and unseeded units at Mt. Trumbull following ecological restoration treatments.

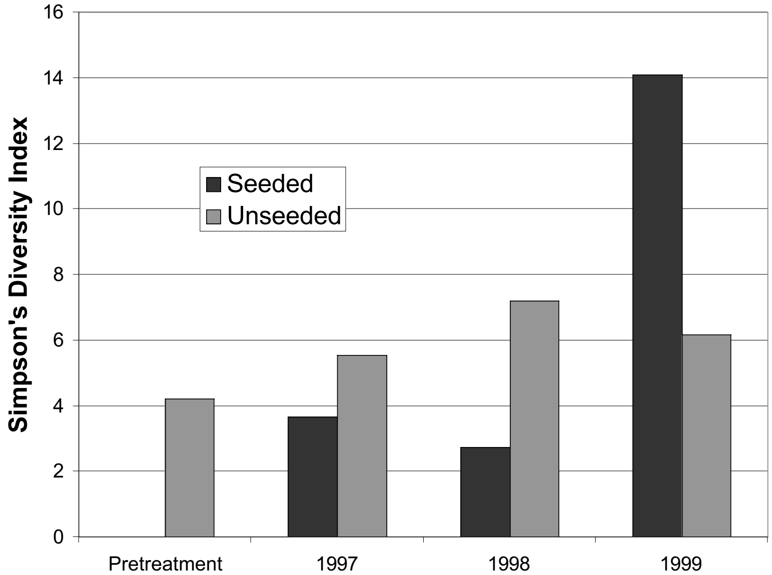

Figure 3—Simpson's diversity index (SI) in the seeded and unseeded units at Mt. Trumbull following ecological restoration treatments.

deer populations and/or domestic livestock in the late 1800s and early 1900s. Native shrub species also were decimated from much of the Plateau, presumably by fluctuations in the deer population. The Mt. Trumbull area has populations of deer but no elk, and it has a history of grazing by domestic cattle (Altschul and Fairley 1989). Seeding can return extirpated species to a site, although information is necessary to ascertain if these species were historically present. If species have been decimated from a site, then the genetic material from species adapted to that site is likely no longer available.

Nonnative species, particularly cheatgrass and common mullein, increased following restoration treatments in the study area at Mt. Trumbull. Common mullein is considered to be an early-successional species and is expected eventually to be replaced by native species in the treated areas, but cheatgrass has been known to change the species composition and fire cycle of areas where it has become dominant (Sheley and Petroff 1999). If the goal of management efforts is to decrease the amount of cheatgrass in the restored areas, then these areas should be heavily seeded with early successional native grass species able to compete with the cheatgrass, such as squirreltail (Jones 1998). Early successional species made up a large percentage of species in the soil seed bank in the study area (Springer 1999). Their decline after the first few years was expected because many of these species are annuals or biennials, rely on disturbance to maintain their populations, and use the soil seed bank to store genotypes for future environmental variability (Springer 1999). However, the low frequency of perennial species in the unseeded unit is of some concern if this pattern is indicative of the entire study area.

Species richness and diversity began to drop off in the unseeded unit in the third year following restoration treatments, and few new species were recorded. This trend could be attributable to weather or to a slowdown in the rate of successional response after treatment. Both units should continue to be monitored to observe trends. As additional units across the entire project area are treated with overstory tree thinning and prescribed burning, more data will be available to assist with management decisions.

This study points to the need to conduct seeding trials to determine which seeds are germinating, and how long it takes for these species to become established. Seeding trials can also be used to pinpoint the origin of nonnative species appearing onsite, whether through dispersal mechanisms or in seed mixtures. There is also a need to conduct studies to determine the effects of prescribed burning on leguminous species in Southwestern ponderosa pine forests, as well as the inputs of nitrogen by these species, for their role in nitrogen cycling is just beginning to be quantified (Hendricks and others 1999).

When considering whether and with what species a site should be seeded, each area needs to be treated individually and blanket treatments should not be applied to huge areas of the landscape. Factors to take into account are existing vegetation, species in the soil seed bank, past management history, microclimate conditions and soils. Soil seed bank samples taken prior to ecological restoration treatments can give an idea of the species that will colonize a site following these treatments (Springer 1999). As the demand for native seed increases across the West, we hope that supply will grow to meet demand and eventually costs will decline; however, there is a tradeoff of cost versus maintaining seed mixtures that are weed-free. Further effort should be made to collect seeds in areas undergoing restoration to maintain the genetic material adapted to that area.

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