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Working Papers in Southwestern Ponderosa Pine Forest Restoration

Understory Seeding in Southwestern Forests Following Wildfire and Ecological Restoration Treatments

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Ecological restoration is a practice that seeks to heal degraded ecosystems by reestablishing native species, structural characteristics, and ecological processes. The Society for Ecological Restoration International defines ecological restoration as "an intentional activity that initiates or accelerates the recovery of an ecosystem with respect to its health, integrity and sustainability….Restoration attempts to return an ecosystem to its historic trajectory" (Society for Ecological Restoration International Science & Policy Working Group 2004).

In the southwestern United States, most ponderosa pine forests have been degraded during the last 150 years. Many ponderosa pine areas are now dominated by dense thickets of small trees, and lack their once diverse understory of grasses, sedges, and forbs. Forests in this condition are highly susceptible to damaging, stand-replacing fires and increased insect and disease epidemics. Restoration of these forests centers on reintroducing frequent, low-intensity surface fires—often after thinning dense stands—and reestablishing productive understory plant communities.

The Ecological Restoration Institute at Northern Arizona University is a pioneer in researching, implementing, and monitoring ecological restoration of southwestern ponderosa pine forests. By allowing natural processes, such as fire, to resume self-sustaining patterns, we hope to reestablish healthy forests that provide ecosystem services, wildlife habitat, and recreational opportunities.

The ERI Working Papers series presents findings and management recommendations from research and observations by the ERI and its partner organizations. While the ERI staff recognizes that every restoration project needs to be site specific, we feel that the information provided in the Working Papers may help restoration practitioners elsewhere.

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Introduction

Shrubs, grasses, sedges, and forbs form the understory of ponderosa pine and pinyon-juniper ecosystems. They cover the natural openings in these two ecosystems—openings that were much more extensive historically than they are today. While restoration treatments in these ecosystems typically focus on trees, it is also important to restore the natural diversity and productivity of the understory plant community because a healthy understory provides wildlife habitat and fuel for low-intensity fires that maintain forest structure.

Restoring a healthy understory may require little or a great deal of effort, depending upon the site conditions and site history. Many sites still support some native understory species, either living or in the seedbank, in which case thinning of overstory trees and conducting some prescribed fires is often enough to promote the growth of a healthy understory. In situations where the treated area is adjacent to a weed-free area with a highly diverse understory, it may be possible to simply let nature reseed the treated site. Still other sites lack native understory species and their seeds, in which case it may be necessary to reintroduce those species as either seeds or seedlings. In this working paper, we cover this last situation—one where active seeding is needed.

Some Cautions

Before discussing the use of seeds to restore a ponderosa pine or pinyon-juniper understory, several points of caution need to be raised. First, the arid and semi-arid climates of the Southwest make seeding of almost any species a risky enterprise. The vagaries of temperature and rainfall are especially acute in the region, and success often depends on a bit of luck along with well thought-out plans and precise implementation. Second, seed availability is often limited due to a variety of factors, not the least of which are crop failures due to climatic variations, unusually high demand for seed during years when large restoration or rehabilitation plantings occur, and a dearth of native seed suppliers in the region (Bermant and Spackeen 1997). Third, seed predation by birds and rodents can seriously reduce the level of germination (Nelson et al. 1970). Fourth, weedy contaminants in seed mixes and single–seed allotments can cause problems by introducing additional and unexpected competition, especially from invasive plants (Keeley et al. 2006). Fifth, serious ecological problems can arise when using seed that is not genetically similar to local, native species (Belnap 1995, Jones and Johnson 1998, Barclay et al. 2004, Beyers 2004).

Nevertheless, successful seeding can: 1) increase native species diversity, richness, and/or cover; 2) improve wildlife habitat and/or forage for livestock; 3) provide competition to invasive, non-native species; 4) improve soil quality; and 5) aid in erosion control.

Basic Tasks

The process of seeding following wildfire and ecological restoration treatments involves five general tasks: 1) obtaining seed or other plant propagules, 2) developing seed mixtures, 3) conducting site preparation, 4) implementing the planting, and 5) monitoring and adaptive management.

Monsen and his colleagues (2004) provide some basic principles for planning and implementing rangeland revegetation projects. Many of these principles are also relevant to seeding in ponderosa pine and pinyon-juniper ecosystems. While it may be impossible to attain all these goals, the more that can be put into practice, the more successful a project will be. The principles, slightly modified from Monsen's originals, are as follows:

- The proposed changes to the plant community must be necessary and ecologically attainable.
- The choice of species should support the goals and objectives of the project.
- The terrain and soil must support the desired changes.
- Precipitation or irrigation (Bainbridge 2007) must be adequate to assure establishment and survival of seeded species.
- Competition must be controlled to ensure that planted species can establish and persist.
- Plant only site-adapted species, subspecies, and varieties.
- Consider planting a multi-species seed mixture.
- Use sufficient seed of acceptable purity and viability.
- Plant into a well-prepared seedbed and cover the seed approprately.
- Plant during the season that provides the most favorable conditions for establishment.
- Newly seeded areas must be managed properly to avoid harmful effects, such as herbivory and human-caused injury to new seedlings.

Obtaining and Storing Seeds

Most agencies, institutions, and individuals in the Southwest buy seed for their revegetation and restoration projects. Buyers should talk with suppliers and confirm the type of seed (e.g., wild collected or cultivated) and its geographical source (e.g., either in terms of a physical location or whether the seed is source-certified). They should keep in mind that, as a general rule, the farther north or south the seed source is from the restoration site, the less likely the plant material collected at the source will be able to adapt to the conditions at the restoration site. In the Southwest, purchased seed should come from areas that also experience a precipitation pattern that includes summer monsoonal moisture as well as winter precipitation. Buyers should make clear to the supplier the exact species they want, and the other specifications of their purchase, especially the Pure Live Seed rate, moisture content, cleanliness, packaging, and delivery date. A seed delivery checklist should be used to confirm that the specifications have been met. This information can be used to verify that the supplier should be paid or to reject a seed delivery or discuss partial payment with a supplier.

If purchased seed will be stored for any length of time before seeding, it should be handled carefully, stored in paper, poly or cloth bags, and kept from excessive light, heat, cold, and moisture. A cool, dry, ventilated place free of insects and rodents is best. Pre-storage treatment (either freezing or use of an insecticide or dessicant) can help prevent loss of seed. Stored seed should be labeled and dated, and its whereabouts tracked in a database.

An alternative approach for obtaining seed is to collect it at or near the restoration site and ship it to farms or ranches where it can be irrigated, grown, harvested, and then shipped back to the restoration site for planting (a method call "seed increase"). While the cost of such an operation can be as much or more than buying seed from a supplier, this approach does have the advantages of supporting local farmers and ranchers and producing genetically appropriate, weed-free seed that is specific to a restoration site.

This paper is not large enough to cover the seeding and propagation requirements of each individual species found in southwestern ponderosa pine or pinyon-juniper ecosystems. For information on individual species, see Young and Young (1986) and Baskin and Baskin (1988) or contact the nearest Natural Resources Conservation Service Plant Materials Center for information on germination requirements, or go to their web site at http://plant-materials.nrcs.usda.gov. Another good source is the Native Plants Propagation Protocol Database at http://www.nativeplantnetwork.org/network.

Developing Seeding Mixes

The general rule for developing a seed mix is to use sufficient seed to produce the desired understory without wasting seed or money. The amount of seed used in any mix is influenced by the species used, seed purity, seed viability, the condition and type of seedbed, the method of seeding, the amount of competing vegetation present, and the project objectives (Monsen et al. 2004). It is also influenced by the size of the area being seeded, the topography, elevation, soils, and knowledge of which species have worked best in similar situations in the past. Managers who have access to existing reference sites (e.g., research natural areas) that are physically comparable to the restoration site should consider using them as guides for developing the species composition of a seed mix. Historical information about understory species can likewise be used, either independently or in conjunction with reference site information.

Seed Viability and Pure Live Seed

Knowing whether a seed is viable indicates whether it will germinate. A simple viability test for grass seed involves checking the seed to see if it has entered the hard-dough stage. Seeds in the hard-dough stage are plump and firm, and will not exude endosperm when pressed between the nails of the thumb and forefinger. Another method is to take a small sample of seeds, germinate them, and then calculate the percentage that germinated from the total planted. Many people and organizations use a lab test in which a sample of seeds is soaked in a tetrazolium solution (TZ) that causes the seed embryos and cotyledons to turn dark red, if they are viable. Protocols for seed testing have been established by the Association of Official Seed Analysts, Inc. and the International Seed Testing Association.

Seeds are generally sold on a Pure Live Seed (PLS) basis. The PLS of a species indicates its germination rate and how pure the seed is (amount of desired seed compared to the amount of weed seeds, chaff, and other non-viable material). The calculation for PLS is:

$$\text{PLS} = \text{percent germination x percent purity} \div 100$$

To put this formula in less abstract terms, suppose Seed Lot A is labeled 98% pure with a 95% germination rate and Seed Lot B is labeled 89% pure with a germination rate of 92%. To obtain the PLS for Seed Lot A, multiply 98 by 95 and divide the result (9,310) by 100. This gives Seed Lot A a PLS of 93%, which means that 1.08 pounds of the seed will have to be purchased to get 1 pound of pure live seed. Using the same formula for Seed Lot B, the PLS is 82%, which means that 1.22 pounds of the seed will be needed to obtain 1 pound of pure live seed.

In addition to knowing the PLS, it is necessary to determine the number of seeds per unit area that will be required for a successful planting. This number is usually between 20 and 40 seeds per ft^2 (871,200-1,742,400 seeds/acre) for diverse mixes (Diboll 1997, Monsen et al. 2004), although 6 seeds per ft^2 (261,360 seeds/acre) is a more appropriate rate for those species that spread quickly (Monsen et al. 2004). Determining this rate depends on the type of ecosystem or plant community being restored, the number of species in the overall mix, the germination potential of the species being used, and the project budget. Typically, seeding rates per unit area are increased for sites with poor soils, steep slopes, low moisture, excessive competition from weeds, and/or excessive herbivory. Likewise, more seeds may be appropriated for species that are slow to establish or those with tiny seeds (Table 1). Shrubs seeds, on the other hand, may be applied in fairly small amounts. Keep in mind that it is possible to seed too heavily because there may be intense competition for moisture and nutrients if too many seeds germinate.

Calculating Seeding Rates

To determine the seeding rate (expressed as the number of pounds/acre) needed for planting a single species, multiply the number of seeds per ft^2 times 43,560 ft^2 (the number of ft^2 in an acre), and then take that number and divide it by the product of the number of seeds per pound times the PLS times 0.01. The formula looks like this:

$$\#\text{ of seeds per ft}^2 \times 43{,}560\text{ ft}^2 / \#\text{ of seeds per lb} \times \text{PLS} \times 0.01$$
$$= \text{lbs/acre of seed required}$$

For example, if the goal is to plant a pure stand of grass at 40 seeds per square foot, when there are 128,000 grass seeds per pound and a PLS of 90, the calculation would be as follows:

$$40 \times 43{,}560 = 1{,}742{,}400 \text{ total seeds/acre}$$
$$\div$$
$$128{,}000 \times 90 \times 0.01 = 15.125 \text{ lbs/acre}$$

Calculating for a multiple-species mix is more complicated and requires the planner to determine a proportion for each species in the mix. This proportion, which can be represented by a percentage, is then multiplied by the number of desired seeds per square foot for the entire planting. Once that number is arrived at, then the formula used above for a single species can be applied to all the species in the seed mix.

The box below provides a simple example of a multiple-species calculation in which the desired number of seeds per square foot is 50.

Species	A	B
% desired proportion	60	40
seed per ft^2	30 (60 percent of 50 seeds)	20 (40 percent of 50 seeds)
PLS	75%	95%
# of seeds/lbs	60,000	280,000

The number of pounds per acre for Species A is calculated as follows:

$$30 \times 43{,}560 = 1{,}306{,}800 \text{ seeds/acre}$$
$$\div$$
$$60{,}000 \times 75 \times 0.01 = 45 \text{ lbs/acre}$$

The calculation is the same for Species B, but produces dramatically different results:

$$20 \times 43{,}560 = 871{,}200 \text{ seeds/acre}$$
$$\div$$
$$280{,}000 \times 95 \times 0.01 = 3.3 \text{ lbs/acre}$$

When working with a diverse mix, the planner often aims for a mixture of grasses and forbs (e.g., 60/40) that will ensure there are adequate fuels (grasses) to carry fire and enough forbs for plant diversity and wildlife purposes. Because this type of mix may include many species, all of which have different numbers of seeds per unit measure, different potentials to germinate and different competitive abilities, the calculations become much more complex and often require recalculations to arrive at a mix that will satisfy the overall goals of the project. The competitive ability of the species in a mix should be determined prior to calculating rates within the mix (see Monsen et al. 2004, Chapter 17, Table 12 for an extensive list of the competitive abilities of various species; Table 1).

Multiple-species and Single-species Mixes

Multiple-species mixes provide several advantages, including: 1) the development and maintenance of diverse plant communities, 2) an opportunity to move plant communities through desirable successional changes, 3) improved weed control, 4) providing a better chance for species establishment, and 5) allowing multiple values such as improved wildlife habitat, forage production, aesthetics, and hydrology to exist in one place. Multiple-species mixes are also self-supporting. For example, sowing nitrogen-fixing legumes will, in many cases, improve the vigor and growth of other plants in the mix and improve the soil quality.

There are cases where seeding a single species might be warranted (Monsen et al. 2004). These situations arise when planting difficulties, limited budgets, and lack of seeds occur. Rather than seeding slow-growing species at heavier rates in these areas, they should be planted in areas separate from fast-growing herbs or grasses.

Nurse Crops

Nurse crops help the early growth of desired species and are commonly used in degraded habitats that have extreme environmental conditions (arid or alpine habitats) or in areas with a large number of herbivores. They protect and shelter young seedlings from the harsh environment and some species provide a refuge from herbivory (Padilla and Pugnaire 2006). Nurse crops are typically short-lived species whose numbers decrease or fall to near zero as the planting matures, often the first year or two after planting. Their planting rates should be calculated separately from the rates of any other planting mixes.

Nurse crops are sometimes used to provide cover, particularly for shrub establishment or to control erosion (rapidly germinating species are commonly used for this latter purpose). However, the complexity of competition and facilitation makes it difficult to determine if the nurse plants will benefit the restoration or not. As a general rule, the harsher the environment or the stronger the pressure from herbivory, the more beneficial nurse plants may be. Additional research is necessary with a number of species and on a long-term basis before conclusions can be drawn.

Table 1. The number of seeds per pound for commonly used species in ponderosa pine and pinyon-juniper restorations and rehabilitation plantings. Sources: USDA Plants Database and the Ecological Restoration Institute Herbaceous Plant Database (Jan Busco).

Scientific Name	Common Name	Seeds/lb	Seed spread rate	Storage longevity (yrs.)
Grasses				
Achnatherum hymenoides	Indian ricegrass	235,000	moderate	
Bouteloua curtipendula	side-oats grama	159,200	slow	
Bouteloua gracilis	blue grama	724,400	slow	
Elymus elymoides	squirreltail	192,000	slow	
Elymus trachycaulus	slender wheatgrass	135,000	slow	
Festuca arizonica	Arizona fescue	480,500	slow	
Pascopyrum smithii	western wheatgrass	135,000	slow	
Poa fendleriana	muttongrass	2,000,000	slow	
Poa secunda	Sandberg bluegrass	2,000,000	slow	
Schizachyrium scoparium	little bluestem	240,670	moderate	
Sporobolus cryptandrus	sand dropseed	5,600,080	rapid	
Forbs				
Asclepias tuberosa	butterflyweed	70,000	slow	<5
Balsamorhiza sagittata	arrowleaf balsamroot	58,000	slow	5-7
Eriogonum spp.	wild buckwheat	120,000	moderate	10-15
Linum lewisii	Lewis flax	295,000	slow	7-10
Lupinus argenteus	lupine	126,000	rapid	
Penstemon barbatus	bugler penstemon	550,000		4-6
Penstemon palmeri	Palmer's penstemon	586,000	slow	4-6
Penstemon strictus	Rocky Mt. penstemon	490,000	slow	4-6
Sphaeralcea parvifolia	smaller globemallow	850,000		16+
Shrubs				
Atriplex canescens	four-wing saltbush	44,000	slow	20+
Cercocarpus montanus	mountain mahogany	47,000	slow	
Krascheninnikovia lanata	winterfat	111,000	rapid	2-3

Seedbed Preparation

The two main objectives of site preparation are 1) to reduce undesirable plant competition and 2) to create conditions for the greatest levels of seed germination and plant survival. Good seedbed preparation requires a thorough knowledge of the site, including the land use history, soil characteristics, and existing vegetation. Although proper seedbed preparation will increase seed germination and plant survival, it is often not done due to limited time or financial resources, rocky soils, or a lack of proper equipment.

Eliminating or controlling non-native plant competition is especially important in semiarid regions where moisture and nutrients are limited. This is typically done in the Southwest with herbicides appropriate for eliminating or controlling the problem plants.

Seedbed preparations that create places to trap high numbers of seeds, increase surface roughness, provide a wind barrier while minimizing soil disturbance, and/or increase moisture availability are desirable. Dragging a small chain behind an ATV or small tractor and/or harrowing across the soil surface usually creates microsites that will capture seed and enhance seed germination. Land imprinters and pipe harrows can be used in larger areas of pinyon-juniper. Rough surfaces tend to capture seed, with large holes capturing the most seeds. The most favorable water and temperature conditions for germination occur within cracks, depressions, rocks or gravel, plant litter or mulch, or vegetation that serves as nurse plants (Call and Roundy 1991). Ideally, the prepared soil will be loose on the surface but firm beneath.

Because soil moisture is critical to seed germination, seedbed preparation with any soil-disturbing device must be done at times that minimize soil moisture loss. In most situations in the Southwest, this means conducting seedbed preparation just prior to when a site will receive most of its precipitation. Typically this means doing the preparation in the fall and coordinating it with a late-fall planting or just prior to summer monsoon rains.

Litter and mulch also provide desirable microsites for seedling survival as long as they are not too deep or heavy. Litter generally modifies air temperature and relative humidity at the soil surface. It also delays soil water depletion in the surface soil layer (Call and Roundy 1991). Neighboring plants, particularly shrubs, may provide favorable sites for seedling establishment. However, they can also compete for limited water resources.

Various soil amendments, such as mulches, tackifiers and mycorrhizal inoculants, have been shown to have varying degrees of success and are extremely site-dependent. Any new method should be tested on a small scale before being applied to a large site. Inconsistent results have been obtained from fertilization of wildland areas. In fact, high nutrient levels may result in depleted soil moisture reserves due to the rapid growth of nitrogen-positive species, particularly annuals and, in some cases, invasive non-natives.

Restoring or revegetating areas burned by wildfires typically does not require seedbed preparation if the seeding occurs immediately after the fire and in areas where ash can be used as a seedbed. Based on their work in Montana, Goodwin and Sheley (2001) found that broadcast seeding directly into the ash layer in the late fall and immediately after a fire produced the most successful burned-area revegetation efforts. They also noted that, if the ash layer is absent, such areas benefit from seeding done with a no-till drill.

Seeding Techniques

There are several basic seeding methods—broadcast (by hand or machine), drilling, hydroseeding, aerial, spot seeding, and interseeding. Each has its place, and the land manager should carefully consider the site conditions as well as the logistics and expense of each method before choosing one.

Broadcast

Broadcast seeding can be done either by scattering seed by hand or by using any number of mechanical seed broadcasters including those that strap across the chest and dispense the seed as you walk and turn the machine's hand crank, fertilizer spreader types that can be pushed or pulled across the ground, or broadcast seeders that are pulled behind a tractor or ATV. Broadcast seeding is one of the most popular and least expensive methods, and one that can be used on sites that are inaccessible or inhospitable to machine-seeding operations. However, seeding rates need to be significantly higher (twice the rate used for drilled seeding) due to the lower germination rates typically observed when using this method.

Broadcast seeding should be done immediately after final site preparation, and before firming the seedbed with a cultipacker or by dragging small chains across the site. To ensure complete coverage of the site, divide the seed mix into two parts and apply the first part in a north-south direction and the second part in an east-west direction, walking or moving the machinery at as steady a pace as possible. Windy days are not recommended for broadcast seeding. Broadcast seeding on steep slopes without a follow-up method that covers the seed with soil should be delayed until a snow cover developes.

Drilling

Planting seed with a seed drill or imprint planter is a very effective method for putting the seed into the ground at the correct depth. As a result, drilled or imprinted sites typically produce greater germination rates than broadcast sites. Planting this way is also quite efficient because the machine places the seed across the site at an even rate and it can be done on windy days. Unlike broadcasting, seed drilling should be done immediately after preparing the site and after the seedbed is firmed by roller packing. Seed drills have four drawbacks. First, they may not work on all sites, especially those that are uneven, rocky, have bedrock near the surface, or have an abundance of woody debris—as is the case with most ponderosa pine sites. Second, they are expensive and require other equipment (tractors or ATVs) to pull them. This can be overcome by borrowing or cost-sharing equipment. Third, seed drills require clean seed (awnless and without chaff), otherwise the seeding tubes become plugged and must be cleaned. Fourth, drilling may not be acceptable on sites with other resource concerns, such as concentrated archaeological sites.

Hydroseeding

Hydroseeding requires access roads and specialized machinery—equipment that applies a slurry of seeds, wood fiber, fertilizer, and watery emulsion to a site. It is used on slopes where erosion is a primary concern or on flat sites where having enough moisture for germination is a problem. The process can involve one or multiple steps. If all the ingredients are applied at once, then the seeding rate needs to be increased; the multiple step process applies the seed first, creating better contact with the soil, and then applies the remaining slurry. Mulch is applied when either method is used to seed slopes. When applied to a slope, the surface should be furrowed parallel to the slope. Typical average costs (including a typical seed mix) vary from $300 per acre on flat sites to $1,600 per acre for moderate to steep slopes (State of California Department of Transportation 1999).

Aerial

Aerial seeding can be done with either a fixed-wing aircraft using a Venturi spreader or by helicopter using a tethered rotary spreader. Aerial seeding with an airplane has the advantages of being able to uniformly cover extensive areas in a relatively short time and operating across terrain that is inaccessible to people or ground-based equipment. Helicopters, while slower than planes, work well in mountainous areas and on irregularly shaped sites. Windy conditions can be problematic for either type of aircraft in terms of distorting the application pattern. Access to this specialized equipment may also be problematic.

Spot Seeding and Interseeding

Spot seeding is a good way to introduce species that have small seeds and/or are expensive, or seeds with special germination requirements. Monsen et al. (2004) report that spot seeding following chaining on pinyon-juniper sites is a successful method. Spot seeding into existing pits and depressions is also recommended.

Interseeding involves seeding into the existing groundlayer of a remnant or recently restored site and is used to improve the species composition (Stevens 1980, Packard 1997). This can be done using single species or mixes of species. Judiciously selective seeding in protected habitats and microclimates is a loss-prevention technique used successfully by foresters in the Southwest and can also be applied beneficially to understory restoration projects (Jan Busco 2001, pers. comm.). No preparation is needed in areas of sparse open vegetation, while burning or mowing is required in areas where the cover is dense enough to significantly shade the ground during any part of the growing season. Seed should be sown during the season when it is most likely to germinate and survive. As in spot seeding, looking for, and planting into, microsites that will foster germination is recommended. Don't waste seeds in brushy areas or areas with aggressive weeds.

Planting Depth

Seeds geminate best when planted at a proper depth (typically between 0.25" and 0.75") in a firm seedbed (Call and Roundy 1991). Regardless of planting method, seeds should be planted deeper in sandy soils (0.75") than in clay or loamy soils (0.5") (Morgan 1997), although larger-seeded species can be planted a bit deeper. Generally, seeds of most species should be covered with about 2.5 to 3 times their thickness in the cleaned state (Monsen et al. 2004). Species that need exposure to light to germinate, such as winterfat (*Krascheninnikovia lanata*), sagebrush (*Artemesia* spp.) and penstemon (*Penstemon* spp.), should be surface seeded and then firmed or pressed into the soil surface.

Best Time to Seed

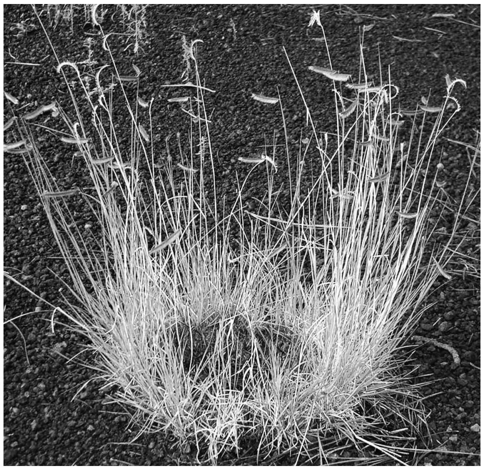
Seeding commonly fails in areas of the Southwest for two main reasons: 1) intense monsoon storms wash seeds away before germination can occur, and 2) young seedlings die during dry periods.

While the best time to seed varies by species, restorations of any scale beyond a small garden typically require planting most of the species in a seeding mix at the same time. If a seeding project in a southwestern forest must be done in a single event, the best time to seed is just prior to the summer monsoon (mid-June to early/mid-July for a typical year) (Lavin and Springfield 1955) or in October and November (Monsen et al. 2004). A dependable heavy snowfall will increase the chance of a successful fall planting (Lavin and Springfield 1955). Predation by rodents is also decreased with late-fall plantings.

Other Forms of Seeding

Although not as well known, seed balls, fecal seeding, and gully seeding provide alternatives to traditional seeding methods. Seed balls are an old method of seeding in arid environments. A seed ball is a mixture of clay, compost/soil humus, seeds, and water that is formed into a ball and tossed on the ground where it stays inert until sufficient moisture occurs causing the seeds to germinate and grow. The Pajarito Plateau Watershed Partnership is currently using seed balls to restore areas damaged by the Cerro Grande Fire in New Mexico.

Fecal seeding involves the use of ruminants (cattle, bison, or sheep) as seed-dispersal agents (Barrow and Havstad 1992, Gokbulak 2002, Gokbulak and Call 2004). Seeds of shrubs and/or grasses are fed to an animal and, after two or three days, are deposited in their dung. Barrow and Havstad (1992) suggest that small-seeded grasses, which do not require burial for germination, are best suited to fecal seeding. Gokbulak and Call (2004) report that grass seeds with lower seedling vigor (e.g., Sandberg bluegrass [*Poa secunda*] and bluebunch wheatgrass [*Pseudoroegneria spicata*]) can survive well in the thin dung produced when cattle eat high-quality, high-moisture spring forage. Use native grasses with strong seedling vigor (e.g., Indian rice grass [*Achnatherum hymenoides*] or side-oats grama [*Bouteloua curtipendula*]) when cows are fed drier fall forage.



Researchers in New Mexico (Barrow 1992, Gutierrez et al. 2004) have studied various methods and created different devices for using floodwaters to reseed rangeland gullies and riparian areas. The basic idea is to place seeds in a gully seeder that is located in a drainage way. When rain occurs, the device will be opened at a preset water level, releasing the seeds and allowing the water to move them to sites where they will have the sediment, moisture, temperature, and cover needed for germination. Barrow (1992) reported good germination of alkali sacaton (*Sporobolus airoides*), blue panicgrass (*Panicum antidotale*), and four-wing saltbush (*Atriplex canescens*) using this method.

Monitoring and Additional Research Needs

Long-term monitoring studies and additional research are critical for understanding the best ways to restore understory diversity and productivity. Robichaud et al. (2000) also advocate the need for a better understanding of the response of vegetation to fire in order to increase our knowledge of whether or when seeding may be necessary.

In order to be useful, monitoring data should provide information about how well the goals of the restoration are being met. The questions that provide the basis for establishing a monitoring program are as follows:

- What is the plant community or ecosystem being restored?
- What are the expected functions, structures, and composition of this community or ecosystem during various phases of its restoration?
- What techniques can be used to measure changes in the community or ecosystem?
- What types of change, and at what levels, need to occur over what periods of time before the restoration is a success?

With these questions in mind, a protocol of inventorying and sampling the important components of the restoration can begin, data can be gathered and analyzed, and adjustments to management strategies can be made according to this new information. Since plant communities and ecosystems are dynamic, this adaptive management procedure is essential to maintaining their overall long-term health.

Other Issues to Consider

Benefits of Multiple-year Seedings

Although very little research in the Southwest has been done on seeding in multiple years, this technique may be a desirable way to revegetate plantings that failed due to predation or drought. Packard (1997) reports that planting sections of a site during the course of several years, even decades, is a reasonable alternative to planting the entire site whenever there are constraints involving budget, personnel, or seed. He also suggests planting scattered plantings across a site—areas that will act as "seed islands."

Seed Islands

A "seed island" is an area that serves as a source of propagules for an adjacent restoration area. Very little experimentation has been done with seed islands, although Reever-Morghan and Sheley (2005) found that the two species they planted in seed islands—purple coneflower (*Echinacea purpureum*) and white sagebrush (*Artemisia ludoviciana*)—did recruit into nearby restoration areas. However, Indian breadroot (*Pediomelum* spp.) did not recruit quickly using this method. Additional experimental projects are needed to gain information about the effectiveness of this approach in promoting species diversity in burned areas and sites undergoing restoration.

Protection from Destructive Activities

Because understory plantings can take several years to mature and are a significant investment in time and financial resources, managers need to consider ways to protect them from detrimental activities such as off-road vehicle traffic, camping/hiking, and herbivory. For these reasons and others, newly seeded sites should be protected from such activities for at least the first two to three growing seasons; areas subjected to drought should be protected even longer. Some of the more compatible activities may be reintroduced once the understory is established and healthy, although they should be carefully regulated and monitored.

Seed Limitations

Seed limitation is defined as an increase in population size following seed addition (Turnbull et al. 2000). It tends to occur more commonly in early successional habitats and in early successional species. Seed limitation is becoming of primary concern in restoration of many ecosystems (Young et al. 2005), including southwestern ponderosa pine forests. Several seedbank studies (Vose and White 1987, Korb et al. 2005, Abella et al., 2007) seem to indicate that viable, native seeds are lacking in ponderosa pine forests and, that they, cannot provide a large source of propagules following restoration treatments. Dispersal of seeds can also be limited. Sowing additional seeds often increases numbers of individuals, indicating that there may be more safe sites than available seeds (Young et al. 2005). Long-term monitoring is rarely conducted following seeding studies, so it is not well-understood how long seeded species persist, and whether it is a transient condition.

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Dixon Land Imprinters
http://www.westernecology.com/Imprinters.html

Harold Wiedemann's Reveg Equipment Catalog
http://reveg-catalog.tamu.edu/index.htm

International Seed Testing Association
http://www.seedtest.org

Natural Resources Conservation Service
Plant Materials Center
http://plant-materials.nrcs.usda.gov

Native Plants Propagation Protocol Database
http://www.nativeplantnetwork.org/network

Pajarito Plateau Watershed Partnership: Seed Balls
http://www.volunteertaskforce.org/ppwatershed/Seed%20Ball%20Project.htm

Path to Freedom: Seed Balls
http://www.pathtofreedom.com/pathproject/gardening/seedballs.shtml

USDA Plants Database
http://plants.usda.gov

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