Understory Seeding in Southwestern Forests Following Wildfire and Ecological Restoration Treatments

June 2007
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 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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Series Editor: Dave Egan

For more information about forest restoration, contact the ERI at 928-523-7182 or www.eri.nau.edu
Following Wildfire and Ecological Restoration Treatments

Web Sites
Dixon Land Imprinters http://www.westernecology.com/Imprinters.html
Herald Wiedemann's Reveg Equipment Catalog http://reveg-catalog.tamu.edu/index.htm
International Seed Test Association http://www.seedtest.org
Native Plants Propagation Protocol Database http://www.nativeplantnetwork.org/network
Path to Freedom: Seed Balls http://www.pathoffreedom.com/pathproject/gardening/see=dballs.shtml
USDA Plants Database http://plants.usda.gov

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 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 caused injury to new seedlings. Whenever possible, 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.

Obtaining and Storing Seeds

Most agencies, institutions, and individuals in the southwest buy seed for their revegetation and restoration projects. Buyers should purchase seed from reputable firms that offer a selection of species and are located or are members of an appropriate trade association. It is important to consider the following when selecting seed and seed suppliers:

- Acquire a list of species that are available from reputable seed suppliers.
- Ensure that the seed supplied is pure and live.
- Choose suppliers with a reputation for providing quality seed.
- Request a sample of the seed to be shipped.

Some Basic Tasks
The process of seedling 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.

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- Plant during the season that provides the most appropriate habitat and growth conditions.
- 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.

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- 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.

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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 original, 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.
- Pre-irrigation or irrigation (Rainbird 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.
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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, and cold. A seed, dry, ventilated place free of insects and rodents is best. Pre-storage treatment (either freezing or use of an insecticide or desiccant) 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. A method for planting a 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 Buskin and Buskin (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.cnrs.ars.usda.gov. Another good source is the Web site of the Propagating 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 better 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 seeds to turn dark if, and only 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:

\[
\text{PLS} = \frac{\text{percent germination} \times \text{purity percent}}{100}
\]

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 93 (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 successful planting. This number is usually between 20 and 40 seeds per ft² (870,000–1,742,400 seeds/acre) for diverse mixtures (Dibrell 1997; Monsen et al. 2004), although 6 seeds per ft² (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 required for species that are difficult to establish or those with tiny seeds (Table 1). Suitable 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 seeds per pound) needed for planting a single species, multiply the number of seeds per ft² times 43,560 ft² (the number of ft² 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:

\[
\# \text{ of seeds per ft}² = \frac{43,560 \times \text{# of seeds per lb}}{\text{PLS} \times 0.01}
\]

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:

\[
40 \times 43,560 = 1,742,400 \text{ total seeds/acre}
\]

\[
128,000 \times 0.01 = 1,280 \text{ lbs/acre}
\]

\[
\frac{1,742,400}{1,280} = 1,367.5 \text{ seed/ft}²
\]

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

References
Researchers in New Mexico (Barrow, 1992; Gutierrez et al., 2004) have studied various methods and created different devices for using freshwater to resettle rangeland grazed 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 canecosa*) 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. Robjichak 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 a period of time before the restoration is a success?**

With these questions in mind, a protocol of inventorying and establishing a monitoring program are as follows:

1. Following Wildfire and Ecological Restoration Treatments
2. Undertory Seeding in Southwestern Forests
3. Following Wildlife and Ecological Restoration Treatments

### Undertory Seeding in Southwestern Forests

**Dynamic, this adaptive management procedure is essential to information.** Since plant communities and ecosystems are developing, 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.

### Benefits of Multiple-Year Seedings

Although very little research in the Southwest has been done on seeding in multiple years, this technique may be desirable to create vegetation that failesd due to predation or drought. Parkard (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-Morgan and Shirley (2005) found that the two species they planted in seed islands—purple coneflower (*Echinacea purpurea*) and white sagebrush (*Artemisia ludoviciana*)—did recruit into nearby restoration areas. However, Indian breadroot (*Polidendrum 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 herbicide. 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 subject 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 (Vise 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 seedling studies, so it is not well understood how long seeded species persist, and whether it is a transient condition.

### Scientific Name

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Seed No.</th>
<th>Seed size</th>
<th>Seed weight</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Sporobolus airoides</em></td>
<td>20,000</td>
<td>1/8</td>
<td>43.56 lbs/acre</td>
</tr>
<tr>
<td><em>Bouteloua curtipendula</em></td>
<td>44,000</td>
<td>1/2</td>
<td>45 lbs/acre</td>
</tr>
<tr>
<td><em>Indian ricegrass</em></td>
<td>235,000</td>
<td>3/4</td>
<td>60,000 per acre</td>
</tr>
<tr>
<td><em>Asclepias tuberosa</em></td>
<td>280,000</td>
<td>1/2</td>
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</table>

When working with a diverse mix, the planter 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 fuels 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 must be made carefully 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).

### Multiple-Species and Single-Species Mixes

Multiple-species mixes provide several advantages, including:

1. 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, aesthetic, and hydrology to exist in one place.

Multiple-species mixes are also self-supporting. For example, terrain 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 seedling 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 seedling 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 with degraded habitats or areas suffering from 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. Nurse species provide a refuge from herbivory (Puddil and Furgale 2006). Nurse crops are typically short-lived species whose numbers decrease or fall to near zero as the planted species, often the first year or two after planting. Their planting rates should be calculated separately from the rates of any other planting mix.

Nurse crops are sometimes used to provide cover, particularly for shrub establishment or to create habitat for small animals (gallinaceous species are commonly used for this latter purpose). However, the complexity of computation 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 the 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 gymnocephalum seedings and rehabilitation plantings.

<table>
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<tr>
<th>Scientific Name</th>
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<tr>
<td><em>Balsamorhiza sagittata</em></td>
<td>20,000</td>
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*Echinacea purpurea* (20,000), *Elymus elymoides* (44,000), *Bouteloua curtipendula* (44,000), *Sporobolus airoides* (20,000), *Panicum antidotale* (44,000), *Indian ricegrass* (235,000), *Asclepias tuberosa* (280,000), *Balsamorhiza sagittata* (20,000), *Echinacea purpurea* (20,000), *Elymus elymoides* (44,000), *Bouteloua curtipendula* (44,000), *Sporobolus airoides* (20,000), *Panicum antidotale* (44,000), *Indian ricegrass* (235,000), *Asclepias tuberosa* (280,000), *Balsamorhiza sagittata* (20,000), *Echinacea purpurea* (20,000), *Elymus elymoides* (44,000), *Bouteloua curtipendula* (44,000), *Sporobolus airoides* (20,000), *Panicum antidotale* (44,000), *Indian ricegrass* (235,000), *Asclepias tuberosa* (280,000), *Balsamorhiza sagittata* (20,000), *Echinacea purpurea* (20,000), *Elymus elymoides* (44,000), *Bouteloua curtipendula* (44,000), *Sporobolus airoides* (20,000), *Panicum antidotale* (44,000), *Indian ricegrass* (235,000), *Asclepias tuberosa* (280,000), *Balsamorhiza sagittata* (20,000), *Echinacea purpurea* (20,000), *Elymus elymoides* (44,000), *Bouteloua curtipendula* (44,000), *Sporobolus airoides* (20,000), *Panicum antidotale* (44,000), *Indian ricegrass* (235,000), *Asclepias tuberosa* (280,000), *Balsamorhiza sagittata* (20,000), *Echinacea purpurea* (20,000), *Elymus elymoides* (44,000), *Bouteloua curtipendula* (44,000), *Sporobolus airoides* (20,000), *Panicum antidotale* (44,000).
Summer monsoon rains. Typically this means doing the preparation in the fall and the Southwest, this means conducting seedbed preparation with any soil-disturbing device must be done atBecause soil moisture is critical to seed germination, seedbed preparation is needed in areas of sparse open vegetation, 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 seedling rate needs to be increased; the multiple step process applies the seed first, creating better contact with the soil, and then applies the remaining bury. Mulch is applied when either method is used to seed slopes. When applied to a slope, the seed surface should be firmed parallel to the slope. Typical average costs (including a typical seed mix) vary from $300 per acre on flat sites to $5,000 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 advantage 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 mixtures of species. Ideally selective seeds that protect existing plants and microhabitats are used in this loss-prevention technique successfully used by foresters in the Southwest and can also be applied beneficially to understory restoration (San Buice 2001, pers. comm.). No seed 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 the seedling 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.}

Summer monsoon rains. Typically this means doing the preparation in the fall and the Southwest, this means conducting seedbed preparation with any soil-disturbing device must be done atBecause soil moisture is critical to seed germination, seedbed preparation is needed in areas of sparse open vegetation, 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 seedling rate needs to be increased; the multiple step process applies the seed first, creating better contact with the soil, and then applies the remaining bury. Mulch is applied when either method is used to seed slopes. When applied to a slope, the seed surface should be firmed parallel to the slope. Typical average costs (including a typical seed mix) vary from $300 per acre on flat sites to $5,000 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 advantage 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.

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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 methods are required throughout the 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 done without regard to financial costs, 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 increase moisture availability are desirable. Dragging a small chain behind an ATV or hand tiller across the soil usually creates microsites that will capture seed and enhance seed germination. Land imprinters and pipe harrows can be used in larger areas of priony-juniper. Rough surfaces tend to capture seed, with large holes capturing the most seeds. The loose seed on the surface but firm beneath.

Following Wildfire and Ecological Restoration Treatments

Rough surfaces tend to seed germination. Land imprinters and pipe harrows can be used in larger areas of priony-juniper. Rough surfaces tend to capture seed, with large holes capturing the most seeds. The loose seed on the surface but firm beneath.

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**Other Issues to Consider**

**BENEFITS OF MULTIPLE-YEAR SEEDINGS**

Although very little research in the Southwest has been devoted to seedling development, this technique may be a desirable way to revitalize plantings that failed due to predation or drought. Packard (1997) reports that planting sections of a site during the several courses of 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 Reeves-Morgan and Shirley (2005) found that the two species they planted in seed islands—purple coneflower (Echinacea purpurea) and white sagebrush (Artemisia ludoviciana)—did recruit into nearby restoration areas. However, Indian broomweed (Pseudolimonium sp.) did not recruit quickly using this method. Additional experimental projects are necessary 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 (Turkington et al. 2000). It occurs to tend 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 seedling studies, so it is not well-understood how long seeded species persist, and whether it is a transient condition.

When working with a diverse mix, the planter 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 fuels 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 presents a multiple-species and single-species Mixes calculation in which the desired number of seeds per square foot is 50.

<table>
<thead>
<tr>
<th>Species</th>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td># of seeds per ft²</td>
<td>30 (40 percent of 50 seeds)</td>
<td>20 (40 percent of 50 seeds)</td>
</tr>
<tr>
<td>PLS</td>
<td>73%</td>
<td>95%</td>
</tr>
</tbody>
</table>

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

\[ 30 \times 43.560 = 1,306,800 \text{ seeds/acre} \]

\[ 60,000 \times 75 \times 0.01 = 45 \text{ lbs/acre} \]

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

\[ 20 \times 43.560 = 871,200 \text{ seeds/acre} \]

\[ 280,000 \times 93 \times 0.01 = 1.3 \text{ lbs/acre} \]

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 as degradable habitats and learning 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. Nurse crops 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 plant matures, often the first year or two after planting. Their planting rates should be calculated separately from the rates of any other planting mix.

Nurse crops are sometimes used to provide cover, particularly for shrub establishment or to capture resources (light, nutrients) (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 the 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.

<table>
<thead>
<tr>
<th>Scientific Name</th>
<th>Common Name</th>
<th>Seeds/Lb</th>
<th>Seed spread rate (yrs.)</th>
<th>Storage longevity (yrs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Grasses</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Achnatherum hymenoides</td>
<td>purple needle grass</td>
<td>21.6</td>
<td>slow</td>
<td>4-6</td>
</tr>
<tr>
<td>Agropyron smithii</td>
<td>Smith’s brome</td>
<td>31.4</td>
<td>slow</td>
<td>10-15</td>
</tr>
<tr>
<td>Elymus trachycaulus</td>
<td>blue fescue</td>
<td>24.6</td>
<td>slow</td>
<td>4-6</td>
</tr>
<tr>
<td>Stipa comata</td>
<td>crested wheatgrass</td>
<td>18.1</td>
<td>slow</td>
<td>10-15</td>
</tr>
<tr>
<td><strong>Forbs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asclepias tuberosa</td>
<td>butterflyweed</td>
<td>7.0</td>
<td>slow</td>
<td>4-6</td>
</tr>
<tr>
<td>Cirsium vulgare</td>
<td>Canada thistle</td>
<td>11.0</td>
<td>slow</td>
<td>10-15</td>
</tr>
<tr>
<td>Echinacea purpurea</td>
<td>purple coneflower</td>
<td>39.4</td>
<td>slow</td>
<td>4-6</td>
</tr>
<tr>
<td>Elymus trachycaulus</td>
<td>blue fescue</td>
<td>24.6</td>
<td>slow</td>
<td>10-15</td>
</tr>
<tr>
<td>Solidago virgaurea</td>
<td>false sunflower</td>
<td>17.2</td>
<td>slow</td>
<td>4-6</td>
</tr>
<tr>
<td><strong>Nursery Crops</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gymnosporangium juniperi-virginianae</td>
<td>juniper rust</td>
<td>27.4</td>
<td>slow</td>
<td>10-15</td>
</tr>
<tr>
<td><strong>Annuals</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Acanthospermum</em></td>
<td><em>Acanthospermum</em></td>
<td>7.0</td>
<td>slow</td>
<td>4-6</td>
</tr>
<tr>
<td><em>Agropyron smithii</em></td>
<td><em>Agropyron smithii</em></td>
<td>31.4</td>
<td>slow</td>
<td>10-15</td>
</tr>
<tr>
<td><em>Liquiritia</em></td>
<td><em>Liquiritia</em></td>
<td>24.6</td>
<td>slow</td>
<td>4-6</td>
</tr>
<tr>
<td><em>Poa pratensis</em></td>
<td><em>Poa pratensis</em></td>
<td>18.1</td>
<td>slow</td>
<td>10-15</td>
</tr>
<tr>
<td><em>Plantago major</em></td>
<td><em>Plantago major</em></td>
<td>11.0</td>
<td>slow</td>
<td>10-15</td>
</tr>
<tr>
<td><em>Solidago virgaurea</em></td>
<td><em>Solidago virgaurea</em></td>
<td>17.2</td>
<td>slow</td>
<td>10-15</td>
</tr>
<tr>
<td><em>Thlaspi arvense</em></td>
<td><em>Thlaspi arvense</em></td>
<td>27.4</td>
<td>slow</td>
<td>10-15</td>
</tr>
</tbody>
</table>
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:

$$\text{PLS} = \frac{\text{percent germination} \times \text{percent purity}}{100}$$

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 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 successful planting. This number is usually between 20 and 40 seeds per ft² (87,000–214,000 seeds/acre) for diverse mixes (Dibbél 1997; Monsen et al. 2004), although 6 seeds per ft² (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). 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 or too many seeds germinate.

### Calculating Seeding Rates

To determine the seeding rate (expressed as the number of seeds per ft²/pounds per acre) needed for planting a single species, multiply the number of seeds per ft² times 43,560 ft² (the number of ft² 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:

$$\text{# of seeds per ft}^2 \times \frac{43,560 \text{ ft}^2}{\text{# of seeds per PLS \times 0.01}} = \text{# of seeds required}$$

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

$$40 \times 43,560 = 1,742,400 \text{ total seeds/acre}$$

$$128,000 \times 90 \times 0.01 = 15,125 \text{ lbs/acre}$$

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

### References


Unlikely Seedling in Southwestern Forests

Ecological Restoration Institute

Understory Seeding in Southwestern Forests

Follow Wildlife and Ecological Restoration Treatments

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 seed, 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 called “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 Buskin and Buskin (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 Seed Production 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 competition 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 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 palms 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.
Following Wildfire and Ecological Restoration Treatments

**Introduction**

Shrubs, grasses, edges, 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 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 execution. 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 mixes, 3) conducting site preparation, 4) implementing the planting, and 5) monitoring and adaptive management.

**More阅读**

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 original, 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 appropriately.
- 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.

**Web Sites**

- Association of Official Seed Analysts, Inc.
  http://www.aossaived.com
- Dixon Land Imprinters
  http://www.westernecology.com/Imprinters.html
- Harold Wiedemann’s Reveget Equipment Catalog
  http://reveg-catalog.tamu.edu/index.htm
- International Seed Test Association
  http://www.seedtest.org
- Natural Resources Conservation Service
- Native Plants Propagation Protocol Database
  http://www.nativeplantnetwork.org/network
- Pajarito Plateau Watershed Partnership: Seed Balls
  http://www.volunteerforce.org/ppwp/seedbed%20Ball%20Project.htm
- Path to Freedom: Seed Balls
  http://pathstofreedom.com/pathproject/gardening/seeds/balls.shtml
- USDA Plants Database
  http://plants.usda.gov

**Waiting for a Project**

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

**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 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.


**Web Sites**

- Association of Official Seed Analysts, Inc.
  http://www.aossaived.com
- Dixon Land Imprinters
  http://www.westernecology.com/Imprinters.html
- Harold Wiedemann’s Reveget Equipment Catalog
  http://reveg-catalog.tamu.edu/index.htm
- International Seed Test Association
  http://www.seedtest.org
- Natural Resources Conservation Service
- Native Plants Propagation Protocol Database
  http://www.nativeplantnetwork.org/network
- Pajarito Plateau Watershed Partnership: Seed Balls
  http://www.volunteerforce.org/ppwp/seedbed%20Ball%20Project.htm
- Path to Freedom: Seed Balls
  http://pathstofreedom.com/pathproject/gardening/seeds/balls.shtml
- USDA Plants Database
  http://plants.usda.gov
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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