Native Seed Collection, Processing, and Storage for Revegetation Projects in the Western United States

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Abstract

The foundation of a successful revegetation or restoration program is quality native seed. This requires careful collection, processing, and storage. Mature seed should be collected from healthy, local stands with a sufficiently broad genetic base. Careful identification of the site characteristics and seed-lot tracking are essential. Yearly variation in seed production and seed quality can be very high, and an early determination of seed quality can prevent expensive failures. Nondestructive evaluation using X-rays is effective and economical, but techniques such as staining, inspection, and germination tests can also be helpful. Cleaning, dewinging, and upgrading seed before storage can (1) reduce weight and bulk, (2) improve storage life, (3) increase germination, and (4) make greenhouse production and field planting easier and more economical. The seeds of many native plants can lose their viability quickly if they are not stored under controlled conditions. Seeds in storage must also be protected from rodents, pests, and disease. Dormancy is common in the seeds of many native species, and experimentation is often necessary to determine the best way to break seed dormancy. This can be complicated by year-to-year and plant-to-plant variation.

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Introduction

State and federal laws and regulations are increasingly requiring revegetation with native plants of sites disturbed by mines, highways, and other construction projects. Many state and local governments in the western United States are also using native species for park and highway landscaping projects. In California, increased use of the deserts has resulted in plant and soil degradation, which can best be minimized by revegetation with native shrubs (Kay et al. 1984). These revegetation projects can require considerable amounts of seed. Unfortunately, seed production in desert species is erratic, and seeds of a particular species are often not available for collection from the wild when needed. The establishment of a native seed collection is desirable for assured availability. The California Department of Transportation allows advance seed collection for this reason. If very large quantities are needed, it may be necessary to grow plants specifically for seed production, a process that can take two to ten years. Before a useful seed collection can be established, proper collection, storage, and germination techniques for each species must be known.

Harvesting

Seed quality is highly variable from year to year and should be evaluated before large quantities of seed are collected (Table 1). If the seed quality is very low it may not be worthwhile to collect seed, while high seed quality in a given year may warrant a large collection program. Seed quality can be assessed by nondestructive X-ray analysis, dissection, and germination tests.

For most revegetation projects, it is desirable to harvest seeds from a diverse population. At least 50 plants should be utilized for larger amounts to ensure sufficient coverage of the range of seeds in an area. Jones (1989) found that seeds of *Juniperus excelsa* (Greek juniper) from different maternal plants had significantly different germination rates. To further capture genetic variation, plants should be selected from different stands in a range of comparable sites, because provenance may greatly affect germination and growth characteristics (Hartmann & Kester 1983). Within a stand, it is likely that most individuals are related. If seed is not collected across a broad genetic base, inbreeding will occur. Inbreeding can result in reduced diversity and inferior progeny. Stands are considered different if plants are separated by enough distance to prevent cross-fertilization between populations. Specific pollination mechanisms dictate the appropriate distance for each species. Distance between plants may be relatively unimportant for self-pollinating species, but

Table 1. Color is a good indicator of seed viability in some species.*

	Percentage Filled Seed	
Year Collected	*Dark-Colored Seeds*	*Light-Colored Seeds*
1992	62	4
1991	0	0
1990	97	45

*Percentage filled seed of different-colored *Isomeris arborea* seeds collected at Red Rock Canyon State Park, California (Lippitt 1992).

large separation may be advisable for wind-pollinated plants (200 yards minimum for pine trees) (Lippitt 1991). To prevent inbreeding between insect-pollinated plants, the typical range of the insect pollinator(s) must be considered.

Some shrub species have genetic strains that are resistant to diseases (Schopmeyer 1974). To take advantage of this possibility, it is best to collect seed only from healthy shrubs. Shrubs with desirable phenotypes may be genetically superior (in a specific ecosystem) to neighboring plants with less desirable traits. The seeds of such plants would be more likely to establish themselves successfully in a revegetation project.

Plants that are dominant or codominant (have a fast growth rate and high vigor), will often produce more viable seed (Lippitt 1991). Diseased plants, or plants subjected to environmental stress such as drought, exhibit reduced vigor and usually generate fewer seeds. Some species, however, may produce a stress crop with more seed. Seed vigor may or may not be compromised (Lippitt 1992). Other species may benefit from increased water; for example, native stands of *Simmondsia chinensis* (jojoba) produced many more seeds when provided with supplemental water from microcatchment basins (Ehrler et al. 1978).

Revegetation efforts should use seed from local stands because local genotypes are most likely to succeed and successfully reseed. Seed collected in the vicinity of the revegetation site is preferred. If there is not enough seed available on site, additional genetically appropriate collection sites should be identified (Guinon 1992). The use of genotypes that are not locally adapted can result in immediate mortality, or poor growth and reproductive failure (Dobbs et al. 1976; Guinon 1992). For this reason, the California Department of Forestry and Fire Protection has divided the state into numerous tree-seed zones. Careful consideration has been given to areas with unusual climatic, topographic, or soil conditions that might greatly affect tree or shrub growth (Schopmeyer 1974).

Seed should generally be planted within the same zone and within approximately 150 m elevation (500 ft) of its origin. Some shrubs such as *Atriplex* (saltbush) become so adapted to particular sites that their seeds exhibit poor survivorship when planted in dissimilar sites where local individuals of the same species flourish. For example, *Atriplex* seeds collected at low elevations in the Southwest will not be winter-hardy when planted at northern locations (Young & Young 1986).

Once a stand has been selected, the timing of seed collection can be crucial (Young & Young 1986). For some species, ripe seed is available for several weeks or months; in others it may be available for only a few days. Collection of immature seed results in low seed viability or dormancy and much higher handling costs. Immature seeds are often incompletely developed; some proteins may not have reached a stable conformation that will allow for dehydration without denaturation (Priestly 1986). Enzyme activity is subsequently lost in these seeds, rendering them inviable.

If seed collection is delayed, the seeds are often consumed by various seed predators, such as insects, birds, and rodents. Other seeds are likely to be lost because the seeds of many wild shrubs shatter (fall from the seedhead) rapidly. Some seeds are actively ejected, while others are easily removed by disturbances such as wind. Seeds that ripen and fall quickly can sometimes be collected by placing the seed head in a section of nylon stocking, cheese cloth, or netting. This has worked very well for collecting *Fouquieria splendens* (ocotillo) seeds.

In some cases, it may be possible to collect seeds from the soil surface, but many problems are associated with ground-collected seeds. Seeds gathered from the soil surface are usually of low quality, require excessive cleaning (Young & Young 1986), and may also be contaminated with fungi (Lippitt 1992). If left on the ground too long, fleshy seeds such as acorns may germinate or dry to unacceptable levels. Some species, such as oaks, "abort" or release problem seed early while the rest of the seed is retained on the tree for further ripening. It is usually much better to harvest seed directly from the plant. Bush-collected seed had twice the viability of ground-collected seed of *Larrea tridentata* (creosote-bush) (Fig. 1; Kay et al. 1977). Viability of *Quercus douglasii* (blue oak) acorns collected from the tree was more than double that of ground-collected seed (Phillips 1992).

Harvesting wild plant seed usually requires manual labor because the desired species rarely grow in pure stands, and topography often limits use of mechanical equipment (Young & Young 1986). However, browse-seed harvesters using vacuum suction for collection are being used more frequently. Commercially available leaf and yard vacuums may be of equal value in seed collection. A box-like attachment with a collection bag for rotary line trimmers is also available commercially (Environmental Survey Consulting n.d.). Seed

Figure 1. Harvesting wild plant seed often requires manual labor. A bush collection of *Larrea tridentata,* such as the one shown here, may have twice the viability of ground-collected seed.

clipped from the selected plant is guided into the collection bag by an aluminum box surrounding the cutting head. Further improvement in such machines shows promise in accelerating shrub-seed collection, particularly along roadsides, seeded plantations, and other readily accessible areas (Vallentine 1980). *Atriplex canescens* (four-wing saltbush), which is used for native shrub revegetation in California deserts, has been grown on cultivated agricultural lands offering an alternative to sole reliance on harvesting native stands. The seeds of *Atriplex canescens* can be stripped by tractor-drawn seed strippers (Young & Young 1986).

Small seeds or fruits are generally harvested directly into a container carried or worn by the picker (Schopmeyer 1974). A typical method of manual collection requires holding a bag, tray, or box under the outstretched branches of a shrub while flailing the bushes with a stick or paddle or by sweeping the arms across the upper branches to loosen the seeds, which then fall into the receptacle. The Inyo tray, an aluminum tray 51 cm long by 76 cm wide with a rounded base 20 cm deep, was developed for collecting *Purshia glandulosa* (bitterbush) seeds by hand (Young & Young 1986). A handle is inserted along the long axis. A tough net or plastic bag with a hoop opening can also be used to collect seed. It can be placed over a branch being shaken or held under the branch like the tray.

A Hudson Bay Co. blueberry/cranberry harvesting device has also been useful for collecting seed and pods from wild shrubs (Lippitt 1992). This harvester is an open-topped wooden box with tines along one edge. The device is held by a handle opposite the times and is raked across branches so that the seeds or pods are stripped and fall into the container.

Larger seeds, pods, or fruits can be collected by cleaning or tarping the area under the tree or shrub and then beating down the dry pods with a stick, racquet, bamboo pole, or 1.75-cm (1/2 in) plastic pipe, or by shaking the branches. The pods are then raked or picked up by hand, or concentrated by folding the tarp (Bainbridge & Clark 1987). This is most effective for heavy seeds that will drop to the tarp even in a mild wind. The time and difficulty required to spread the sheeting under the plant limit the value of this collection method.

For spiny shrubs, where the fruits must be physically stripped from the branches, a lightweight, 5–20–gallon barrel provides a ridged lip over which to bend shrub branches for removing fruits. Salad tongs are helpful in collecting cactus fruits and buds.

Leaves, twigs, and other debris collected with the fruit will fragment during drying and processing, increasing the difficulty of cleaning the seed (Schopmeyer 1974). As much debris as possible should be separated during collection.

Processing

Seeds often require cleaning, husking, dewinging, or debearding. Removing soil, leaves, stems, chaff, and other debris from the seeds will reduce the bulk for handling and storage, remove moist material that may cause heating and mold formation in storage, and facilitate flow through seeding equipment (Vallentine 1980). Greater purity also allows more accurate seeding, reducing seed use (Lippitt 1992).

Seeds can be cleaned in the field by hand screening if they are dry enough. The collected material is filtered through a screen with large enough openings to allow the seed or fruit to pass through, leaving coarse debris on top of the screen to be discarded. A second sieving is made with a smaller screen that prevents the desired seed from passing through. The seeds are retained while the fine waste passes through for discarding (Young & Young 1986).

Meat grinders are often used to clean seeds (Fig. 2). Hand separating *Prosopis* (mesquite) seeds from pods can produce several hundred clean seeds per hour, compared to about 7000 seeds per hour using a modified meat grinder (Pasiecznik & Felker 1992). The choice of plate-hole size is important. Large holes (9.5 mm) facilitate material flow but liberate only 20% of the seed. Smaller holes (6.5 mm) free the remaining seed but reduce material flow. Mid-sized holes are not commercially available, but at the California Department of Forestry Reforestation Center in Davis, California, custom hole sizes, plates, and modified sweeps have made meat grinders more versatile. Pasiecznik and Felker (1992) recommend drying *Prosopis* pods at 125°F (52°C) overnight. Because of their high sugar content, fleshy pods must be thoroughly dried or wet-

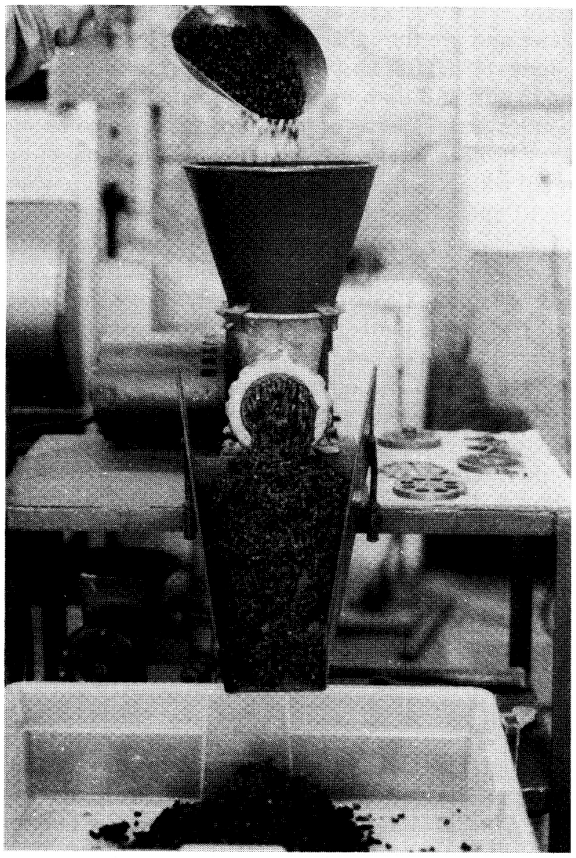

Figure 2. *Heteromeles arbutifolia* (toyon) berries being processed in a modified meat grinder at the L. A. Moran Reforestation Center in Davis, California. The choice of plate hole size is important, and custom hole sizes are often needed.

ted before being fed through a grinder. If the pods are not sufficiently dry (or wet), they can caramelize in the grinder and form a solid mass.

A hammer mill, tumbler, or air separator can be used to remove seeds from chaff and pods. Hammer mills consist of many finger-like hammers rotating inside a section of perforated metal cylinder. The seeds are forced through the holes, separating them from their appendages (Young & Young 1986). Similar machines with brushes, rather than hammers, that rotate inside a screen are more gentle but can still damage some species. *Atriplex canescens* seed dewinged in a hammer mill was easier to plant at proper depths and germinated more rapidly (Vallentine 1980).

Seeds extracted in a mill may already be sufficiently scarified from the action of the mill to germinate readily (Bainbridge & Clark 1987), but mechanical injury can exert a depressing influence on storability (Priestly 1986). Cement mixers and gem grinders have rotating drums with paddles that can dewing seeds (Lippitt 1992). As an alternative, seed can be placed in a mesh bag (or a plastic bag with a few small holes in it), and a compressed air jet can be used to blow the fluff and wings off seeds (Lippitt 1992).

To improve seed purity, weed seeds, the seeds of other plants, and empty seed must be removed. Seeds can be sorted and cleaned using an air separator, which utilizes the movement of air to divide materials according to their terminal velocities (Fig. 3) (Young & Young 1986). A seed's size, shape, surface texture, and density contribute to its terminal velocity. When fed into a rising airstream, seeds and debris of different terminal velocities will separate from each other. The

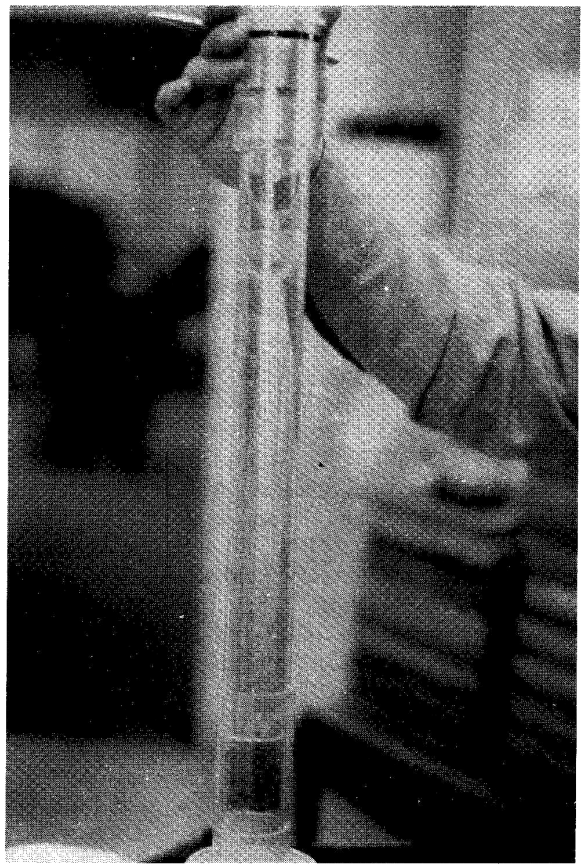

Figure 3. Air separators are very useful for sorting empty from filled seed. In the Dakota Blower–type air separator pictured, a fan (not visible) forces air through a screen at the bottom of the tube. By manipulating the air flow with a rotating valve (at the top of the tube) this worker is separating light, unfilled *Populus fremontii* (cottonwood) seed from the slightly heavier filled seed. Unfilled seed and chaff collect in the cup-shaped receptacles at the top of the tube.

velocity of the airstream can be manipulated to capitalize on the differences between the seeds or trash being sorted. Air separators are available in various designs and sizes.

Disease Control

Insects and fungi are usually controlled by dry, near freezing, or subfreezing storage of seed. Many insects that attack stored seeds were originally from the tropics and have spread and adapted to colder climates by living in man-made seed-storage shelters. Temperatures of greater than 10°C (50°F) are usually needed to develop damaging populations (Young & Young 1986). *Bruchids,* boring insects that may do considerable damage to *Prosopis* seeds on the tree, the ground, or in storage, can usually be controlled by drying the pods immediately after collection and then freezing them to kill the larvae (Bainbridge & Clark 1987).

Sometimes the seed cannot be brought to a cold enough temperature to kill the insects without also damaging the seed. A 20% solution of Malathion in water followed by a drying period and a subsequent dusting with 5% Sevin has proven effective in these cases (Desert Enterprises, personal observation). Kay et al. (1984) used the insecticide Phostox (aluminum phosphide) to protect the seeds of Mojave desert shrubs.

In moist storage at cool temperatures, prestorage fumigation for fungi may be necessary (Schopmeyer 1974). At one time, seed collectors routinely treated seeds with fungicides before storage or prior to sowing (Campbell & Landis 1990). Germinating seeds are very sensitive to chemicals, however, and only a few fungicides—such as captan, thiram, and benomyl—have proven suitable for use on sensitive tree seeds. Fungicidal toxicity may exceed benefits for protection against disease (Edwards 1979). Because of possible toxicity to the seeds, evolution of resistance to pesticides, and adverse effects on human health and the environment, less drastic measures to control seed pests are becoming increasingly popular. Powdered mustard and cinnamon have been used successfully to control mold on stored acorns and may have potential for other seeds. Scented baby powder, added to seeds to improve flow during sowing, is sometimes substituted for the fungicide/repellent Arasan 75 at the Reforestation Center.

As an alternative to fungicides, seeds may be surface-sterilized before storage. Dumroese et al. (1988) reduce the levels of the pathogenic fungi *Fusarium* in *Pseudotsuga menziesii* (Douglas-fir) seeds to negligible levels after a 90-sec microwave hot water soak. Similar heat-treatment seed sterilization has been successful using vegetable oils instead of water as the heating agent. Vegetable oils are not as easily imbibed as hot water and are thought to be less toxic to the embryo.

Jones (1989) used a 1% sodium hypochlorite solution for 15 min and then washed the seeds five times with distilled water. Seeds of many species can also be sterilized by soaking in a 40% solution of household bleach in tap water (two parts bleach in three parts tap water) for 10 min, then rinsed thoroughly in running water for at least 48 hours. A similar procedure can be followed using a 3% hydrogen peroxide solution (Campbell & Landis 1990). Unfortunately, both the bleach and hydrogen peroxide treatments are phytotoxic to many species, so seed should be tested before treatment. Bleaches and other chemicals are generally less phytotoxic to seeds with hard coats. A 48-hour running-water rinse was found to reduce levels of pathogenic fungi to a similar extent as chemical sterilizers without deleteriously affecting seed viability (Lippitt 1992). For the running-water rinse, a shower head is placed in the bottom of a bucket, and an aquarium bubbler is used to increase the concentration of dissolved oxygen and to promote water circulation.

Storage

Although many desert seeds are long-lived and exhibit multiple dormancy mechanisms, other seeds may have their best germination potential at the moment they reach maturity on the plant (Harrington 1988). Some *Salix* (willow) species, for example, are viable for only a few hours. For seed of species that can be stored, proper storage conditions are critical to maintain seed viability over an extended period of time. The two most important factors affecting seed longevity are seed moisture content and seed temperature (Evans 1992). As a general rule, each 1% reduction in seed moisture and each 4°C (10°F) reduction in seed temperature doubles the life of the seeds (Young & Young 1986). To protect from premature germination and seed pests, seeds should be dried as quickly as possible to less than 14% seed moisture and should be stored at a stable humidity below this moisture content. The post-drying moisture content of seeds from a variety of Mojave desert shrub species ranged from 1.5% to 9.4% (Kay et al. 1984). Seedlings do not emerge as quickly from dried seeds, and the seeds require more water and longer time to imbibe and germinate.

Seed moisture content is controlled by storing properly dried seed in tightly closed containers (or doubled 4-mil plastic bags sealed with barlok ties) or by regulating humidity in the storage area (Schopmeyer 1974; Lippitt 1992). Under long-term storage, seed viability is harmed by a high oxygen atmosphere and benefited

by a high carbon dioxide atmosphere (Frankel & Bennett 1967). When seed is sealed in a container, respiration reduces oxygen concentrations and increases carbon dioxide concentrations, creating conditions conducive to long storage life. Moisture in tree and shrub seed had been largely controlled by putting dried seed in closed containers, whereas much agricultural seed is kept in dehumidified storage rooms.

Temperatures can be controlled by storage location, refrigeration, or freezing. Although refrigeration is expensive, it will usually be more cost effective than doing another collection. How long the seed will be in storage and the periodicity of seed production are factors influencing the required storage temperature.

Kay et al. (1984) performed a study to determine if warehouse storage conditions for agricultural seed were as satisfactory as those of closed containers for storing seeds of Mojave desert shrubs. Seeds from the shrubs being stored in hermetically sealed containers were dried for six days at 35°C (95°F), while seed for warehouse storage were not dried after processing. Seeds of most of the 22 species studied showed unchanged or increased germination rates after nine years of storage in hermetically sealed glass containers. Germination for most species stored under warehouse conditions was significantly lower after nine years. *Atriplex canescens* was the only species that exhibited higher germination rates after warehouse storage.

Seed storage must be in containers or facilities that protect the seed from rodents, birds, and insects. Many seed collections have been destroyed by rodents. Breakable glass bottles are better than metal tins, which corrode (Edwards 1979). Shelf systems should be designed with seismic safety in mind.

Processed seed lots often vary widely in quality. Stored seeds must be labeled with detailed information. The label should indicate the species and variety (if known), the precise geographic location of the collection (including seed zone if known), the elevation, soil type, date of collection, and the collector (Vallentine 1980; Stein et al. 1986). The number of stands and individual plants from which the seeds were collected and notes regarding insect damage, seed/pod maturity, and possible poor pollination also contribute to better understanding and processing of a particular seed lot (Stein et al. 1986). Seeds/pound, percentage germination, percentage moisture, and seed treatment and storage conditions must also be included (Lippitt 1992).

Improving Seed Germination

Seed dormancy is an ecologically important device to optimize the spatial and temporal distribution of a species, but it is an obstacle to revegetation efforts where prompt, uniform, and complete germination is often desirable (Rietveld 1989). Nondormant seeds readily pass through three germination stages: (1) imbibition of water, (2) activation of metabolic processes, and (3) growth of the embryo (Schopmeyer 1974). If any of these stages is blocked, the seed remains in a state of dormancy. Impermeability of the seed coat to water or gases, known as hard seededness, is the most common form of seed dormancy and is characteristic of certain families, including the legumes (Schopmeyer 1974). Some notoriously "hard seeded" species such as mesquite often germinate without pretreatment if the seeds are freshly collected but become hard-seeded following drying (Schopmeyer 1974). If the seed imbibes moisture but does not germinate, moist stratification may be needed (Young & Young 1986). If the seed does not imbibe moisture, scarification is necessary. Scarification involves physical or chemical treatments to open the seed coat to allow entry of water.

Scarification can be accomplished by soaking in acid or hot water or by mechanical abrasion. Concentrated sulfuric (H_2SO_4) or hydrochloric (HCl) acid are commonly used to scarify seeds, but many smaller nurseries and propagators are reluctant to use acid. N. T. Mirov designed a simple vessel for use in acid scarification (Young and Young 1986). It consists of a dish made of a stainless steel screen that can be lowered into a glass container by a center pole. A small volume of acid is placed in the bottom of the container, and the seeds are placed into the dish and lowered into the vessel. After the prescribed treatment interval, the dish is raised and the acid is allowed to drain from the seed.

Seeds that have been mechanically cleaned may have a broken seed coat, so milled seeds must be checked carefully before acid dipping to prevent destruction of the seeds (Bainbridge & Clark 1987). Scarification causes a noticeable thinning of the seed coat; if the seed is left too long in an acid bath, a hole will develop in the seed coat allowing acid to enter and kill the embryo (Jones 1989). The length of time required for scarification must be determined by experimentation, and the treatment duration may vary significantly among seeds of the same species. Seed-coat thickness may also change from year to year on the same plant, so the duration of acid scarification must be calibrated each season. *Prosopis glandulosa* (honey mesquite) seeds, for example, require between 3 and 15 min in an acid bath (Bainbridge & Clark 1987). Interspecies treatment lengths vary from seconds to hours, depending upon the nature of the seed coat. Some particularly woody fruits may require a 24-hour acid treatment (Young & Young 1986). Seeds should be thoroughly rinsed following an acid bath.

Some seeds are very easy to damage or kill with acid scarification. Stidham et al. (1980) found that chemical scarification reduced germination in many species of woody shrubs, including *Atriplex canescens*. In addition to removing the seed coat, the process generates considerable heat, which drives moisture from the seed (Young & Young 1986). The reaction temperature can be lowered by prechilling the acid before treatment and cooling the acid-seed mixture during treatment by immersing the reaction vessel in a cool water bath.

Mechanical scarification machines are commercially available. Sharp gravel in a cement mixer may also work, or a feed chute can be used to move seeds onto a sanding disc or drum (Bainbridge & Clark 1987). Small batches of seeds can be scarified by hand, using a file or knife to make a nick or slice in the seed coat. Some care must be taken to avoid injuring the radicle. Seeds that were scarified by sanding showed increased susceptibility to fungus and mold, presumably from the presence of the small particles of seed coat.

A boiling water dip or soak is a common and effective substitute for acid scarification. Most seed processors allow the seeds to soak in boiling water that is allowed to cool. Lippitt (1992) prefers briefly dipping the seeds in boiling water. The boiling water dip is safer than acid scarification, and seed-coat thickness is less of a factor in damage. The same length of treatment can be used from year to year, which is more risky with acid.

If seeds still fail to germinate following scarification, stratification can be used to overcome dormancy. Many seeds with physiological/physical dormancy require exposure to either high or low temperature before being placed in conditions favorable for germination. Cold-moist stratification is most commonly used. In many species, the seed must be fully imbibed before temperature can be effective in breaking dormancy. Stratification works by stimulating embryo growth, removing inhibitors, or both.

The embryos of many seeds fail to germinate because oxygen does not diffuse through the seed coat. Oxygen is more soluble in cold water, so the oxygen requirements of the embryo can be better satisfied during cold-moist stratification (Young & Young 1986). Sometimes oxygen is kept near saturation levels by forcing compressed air through the water. The correct temperature and duration for stratification vary according to the species and must be determined by experimentation. Temperatures generally range from 1 to 4°C (34°–40°F), with duration varying from weeks to months. Any seed lot to be stratified for more than 30 days should be surface-dried after imbibition or periodically surface-dried and then put back into stratification. This procedure can reduce or prevent mold development, which is more likely in the high humidity that exists during long-term stratification (Campbell & Landis 1990; Lippitt 1992).

Plastic bags are good containers for stratification. The seeds can be placed in bags with a variety of substrates, or stratification can occur in bags without substrate—a "naked" stratification (Edwards 1979; Lippitt 1992). Common stratification substrates include moist sand, activated charcoal, vermiculite, or calcined clay (kitty litter) stored at low temperatures (0.5°–10°C; 33°–50°F) until the stratification requirement is satisfied. Substrates help maintain moisture levels in the bag, and some, such as activated charcoal, absorb soluble germination inhibitors (Young & Young 1986). Many desert seeds have water-soluble growth inhibitors that prevent the seed from germinating unless there is sufficient moisture to establish a seedling. If all of the inhibitor is not washed away at once, the seed produces more inhibitor (Bryant 1985). Graves et al. (1975) found that *Ambrosia dumosa* (bur sage; Mojave desert seed sources) germination was improved by stratification in activated charcoal or moist sand at 2°C (36°F) for 30 days.

The observed benefits of stratification often overlap with those of seed priming. Seed priming is a set of techniques to control the amount of water that can be imbibed by the megagametophyte and embryo (Banerjee 1993). The most common form of priming is "osmotic priming" or "osmoconditioning" (Banerjee 1993). Seeds are put into a solution with a high salt concentration, limiting their ability to take up moisture. The seeds absorb enough water to begin preparations for germination but not enough to actually germinate. Seed can be left in the solution until all of the seeds reach the same state (or moisture content), encouraging uniform germination. These germination improvements hold across a range of suboptimal germination temperatures (temperatures commonly used in stratification). Most stratification techniques also manipulate moisture, and they may have priming effects (Banerjee 1993).

Seeds from the desert may require a treatment of high temperature and low moisture (50°C [120°F]/ambient humidity) rather than the low temperature/high moisture (stratification) treatment commonly used (Capon & Van Asdall 1966). High temperature storage appears to promote seed maturation in desert species (Table 2). Seeds show vastly improved germination percentages during the first five weeks of high-temperature storage (compared to seed stored at room temperature), but continued storage at high temperature results in a loss in viability. Seeds stored at room temperature, 20°C (68°F), do not achieve similar germination success until after five months of storage. Thus, if a seed lot is to be planted during the same season that it is collected, it may be beneficial to try short-term

Table 2. Percentage germination of several Mojave and Sonoran Desert annual seeds in response to high temperature (50°C) pretreatment.

	Untreated	*Storage in Weeks*					
Species	*0*	*1*	*2*	*3*	*4*	*5*	*10*
Plantago insularis	100	100	0	0	0	0	0
Sisymbrium altissimum	10	12	13	92	73	71	48
Geraea cacescens	14	60	74	32	34	48	4
Streptanthus arizonicus	0	21	23	29	50	50	30

*From Capon & Van Asdall 1966.

high-temperature storage. If the seed needs to be stored for longer periods of time, lower temperatures may be desirable.

If sufficient information on the seed system is available, appropriate scarification treatments can often be deduced. Seeds dispersed by animals or birds are often amenable to acid scarification. Flood-dispersed seeds (such as *Cercidium floridum,* palo verde) often require mechanical chipping or sanding. Stratification times can sometimes be predicted by winter snow duration or temperature cycling. These estimates can reduce the time required to develop an effective treatment, but they are not always reliable (Lippitt 1992). Some species that do not experience long winters have required a long stratification, for example. *Pinus sabiniana* (gray pine) is native to low-elevation foothills where temperatures are quite mild, but it germinates best after a long (16-week) stratification. *Pinus sabiniana* has a thick seed coat, and thickness of seed coat seems to be as big a factor as winter length. The quality of the seed and the effectiveness of treatments on germination should be recorded on a permanent record (sample seed collection and inventory sheets are available from the authors).

Seed Evaluation/Germination Testing

To determine the value of a seed lot or the rate of seeding needed for a successful planting, every seed batch should be evaluated for purity and percentage of sound seed prior to storage, periodically during storage, and again just before sowing. For seed evaluation, a limited but representative sample should be taken from the entire seed lot. A seed lot is generally defined as a quantity of seed collected from a particular location and elevation at one time. A difference of even a few weeks may make a major difference in maturity or germination percentage. If collections are separated by more than a week, even from the same place, they should be given a different lot number and processed separately. Only after all testing is complete and the two batches are similar enough should they be combined. If the seed lot is stored in several containers, a sample should be drawn from each (Goor 1963; Stein et al. 1986). Seed lots from wild shrubs are rarely homogenous, so the sampling method must produce a representative sample (Stein et al. 1986). Equal storage containers should be subsampled such that the amount taken is proportional to the volume of seed in the container. Seed-lot subsamples are combined into one composite sample.

Bags or containers of free-flowing seed can be accurately sampled with a partitioned probe or trier (Stein et al. 1986). The length of the trier is determined by the depth of the container or bag being sampled. The probe is inserted closed, then opened so seeds from different positions in the container are simultaneously admitted into the slots. Successive thrusts into a container should be along different paths.

Seeds that are not free flowing, such as *Larrea,* and seeds of some other shrub species are usually sampled by hand. An open hand with the fingers held closely together is inserted into the seeds, closed, and withdrawn holding a representative subsample. As with trier sampling, seeds are drawn from well-separated points within each container (Stein et al. 1986).

Purity is determined by inspection and separation of the sample, pure or clean seeds being put aside and weighed separately. Purity can be expressed as the weight of clean seeds of a species divided by the weight of the total sample including impurities.

The percentage of sound seed can be determined by different methods, depending upon the species. X-ray evaluation is a nondestructive method of assessing seed fill and potential viability (Fig. 4). By combining X-rays with cutting tests, it is possible to determine seed quality relatively quickly. A cutting test can be a quick and easy way of determining the number of full seeds, but it requires some experience with the species being tested (Schopmeyer 1974; Lippitt 1992). Seeds are cut open; those with firm, undamaged, fully developed, and healthy looking tissue are considered viable (Fig. 5). Small seeds can be cut by placing them on tape with the sticky side up to prevent the seed from sliding (Goor 1963). In some cases, seeds can be crushed instead of cut. Determination of desert seed quality can be challenging because even dry seeds may be viable.

Sometimes, the viability of a seed can be predicted by external color. Dark seeds of *Isomeris arborea* (bladder pod), for example, are more likely to be viable than the white form. Immature, inviable seed is often light colored (Hanscom 1984). Color may be an effective indicator for determining viability in the field, but it can be less effective after storage. The soundness of many seeds can also be determined by their weight or density. Heavy, well-filled seeds can be separated from

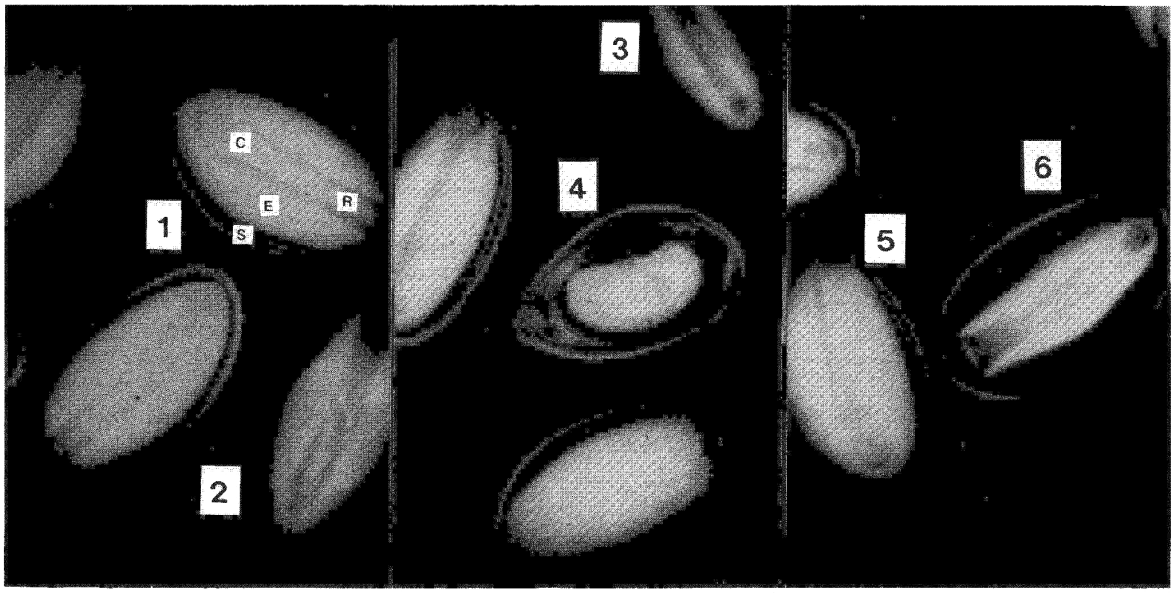

Figure 4. Series of X-ray images of *Pinus strobus* (whitepine). (1) Normal, fully developed seed. Embryo completely fills the embryonic cavity. the cotyledons (C) and radicle (R) parts of the embryo can be easily seen. Endosperm (E) fills the seed coat (S) and provides nourishment for the developing seedling. This seed is germinable. (2 & 3) Incompletely developed seed. The endosperm does not fill the seed coat, and the embryo occupies only a small part of the embryonic cavity. Nongerminable. (4) Insect damage. A seed chalcid larva (*Megastigmus* spp.) has consumed the entire contents of the seed. (5) Another normal, fully developed seed. Germinable. (6) Incompletely developed seed. The embryo still only occupies about 75% of the embryonic cavity. While this seed could be after-ripened to increase the embryo length and development, the poor endosperm condition is likely to make this seed nongerminable.

the empty, immature ones with an air separator (Stidham et al. 1980).

Physiological density separation manipulates water uptake and dehydration rates in seed (Banerjee & Molitor 1993). Viable seeds (with permeable seed coats) actively and rapidly imbibe water and sink quickly. Less viable or unfilled seeds will take up water more slowly and passively (largely through osmosis) and are slow to sink. Thus, timed soaks can be used to effect a separation. Dehydrational density separation works in reverse; viable seeds will more actively retain water, and will be the last to float. This method works for species where physical density separation is inadequate, but it is more time consuming. Water temperature, aeration, and timing of the separation affect the quality of the seed selected by this technique, but periodic cutting tests can determine when an adequate separation has been obtained in relation to the seed lot's potential.

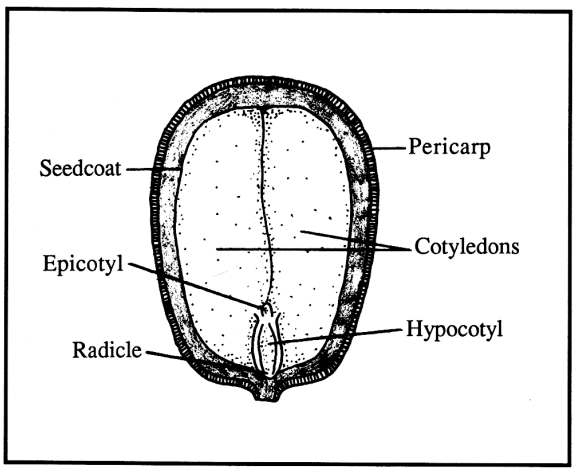

Figure 5. A cutting test is an easy and relatively quick way of determining seed fill. The structures identified on this *Quercus* seed are visible in most healthy dicot seeds (after Olson 1974).

Biochemical stains are available that stain only living tissue. Of these, tetrazolium salts have proved to be the most successful (Schopmeyer 1974). In solution, tetrazolium salts are colorless, but in living tissue they are reduced by dehydrogenase enzymes to form a stable red pigment that is insoluble in water. The localization and proportion of dead, unstained tissue is used to classify seed as potentially viable or inviable. The tetrazolium test is faster than a germination test, but lack of uniformity of staining, failure to detect seeds

that will germinate abnormally, and difficulty in interpreting different degrees of staining are important drawbacks. Testers need a lot of experience with a species before they can obtain much useful information. Tetrazolium stains have proven to be uncertain on seeds with very effective dormancy. They may work better following stratification.

A quick (within one week) growth test that yields results similar to the germination test can be done with the hydrogen peroxide (H_2O_2) test. H_2O_2 stimulates respiration and enhances early germination without the need for stratification (Leadem 1979). The radicle end of seeds is clipped, and the seeds are placed in a 1% H_2O_2 solution. After a 3–4–day incubation, germinated seeds (>1 mm radicle protrusion) are counted and removed. Ungerminated seeds are transferred to fresh H_2O_2 for an additional 3–4 days. The test is terminated at the end of the second incubation period, after all germinated seeds have been counted. The accuracy of this test seems to be species-specific and it often underestimates actual germination (Leadem 1979).

The most reliable method of determining potential germination is a germination test appropriate for the targeted species (Fig. 6) (Schopmeyer 1974). This is effective only when the stratification/scarification requirements are relatively well understood. Seeds used in germination tests should be from lots with at least 98% purity. If the sample is less than 98% pure, then the seed should be separated from debris and tested. The results can then be combined with seed-purity information (Lippitt 1992). The groups of seed are spread on trays of suitable substrate and placed into humid germinators. Alternatively, seed can be placed in enclosed germination dishes or containers where the dishes maintain humidity. Enclosed containers can be advantageous because moisture loss is not a problem as it may be with open trays of substrate. Seeds should be spaced properly (at least 2–5 times the normal seed width) to prevent the spread of fungi, especially in large seeds (Schopmeyer 1974). The proper germination temperature is species-specific and needs to be determined by experimentation.

Figure 6. A germination test is still the most reliable method of determining potential germination but must provide appropriate conditions for germination. Germination test of *Pinus ponderosa* (ponderosa pine) seeds after two weeks. Seeds were germinated under short days (8 hrs light, 40°C; 16 hrs dark, 30°C) in enclosed containers to maintain humidity.

The substrate for germination tests must meet the following requirements: (1) nontoxic to the germinating seedling, (2) relatively free of molds, other microorganisms, and their spores, and (3) adequately aerated and moistened for germinating seeds (Schopmeyer 1974). Now that small cabinet germinators are common, natural substrates such as sand or peat are less often used. Paper substrate, including germination blotters, paper towels, and laboratory filter paper, are more popular. Paper towels sometimes contain germicides, however, which may inhibit germination. Some nurseries use perlite as a substrate because root development is less restricted than on paper and seed can be more easily checked and replaced since roots don't attach to perlite as they do to paper (Lippitt 1992). Published germination standards for seeds such as the rules of the Association of Official Seed Analysts (A.O.S.A.) for seed testing specify the substrate used (A.O.S.A. 1984). Results should be reported on the seed-lot tracking form.

The test substrate must be kept moist enough to provide sufficient moisture for seed germination, though excessive moisture restricts aeration, favors damping off, and inhibits germination (Schopmeyer 1974). For most seeds, if a film of water forms around the seed or a film of water forms on the finger when the substrate is pressed, then the paper is too moist. Placing the paper on a bed of sand can improve aeration. Small amounts of water should be added periodically if the germinator does not maintain high humidity.

The time required for accurate germination tests varies among species, but they typically take between one week and one month, not including treatment to break dormancy. In official testing, germination is defined as "the emergence and development from the seed embryo of those essential structures which, for the kind of seed in question, are indicative of the ability to produce a normal plant under favorable conditions" (Schopmeyer 1974).

Conclusions

Native seeds are essential for successful revegetation and restoration projects. To insure high quality, ma-

ture seed should be collected from healthy, local stands using a sufficiently broad genetic base. Careful identification of the site characteristics and tracking of seed viability over time are essential. Cleaning, dewinging, debearding, and upgrading seed before storage will improve any seed collection.

The seeds of many native plants lose their viability quickly if they are not stored under properly controlled conditions. These can be very species-specific. Proper storage conditions will usually control seed pests, eliminating the need for chemical pesticides.

Multiple dormancy is common in the seeds of many native species, and experimentation is often necessary to determine the best way to break seed dormancy. This can be complicated by year-to-year and plant-to-plant variation. Seed lots should be tested for viability before storage, periodically during storage, and prior to sowing.

The foundation of a successful revegetation or restoration program is quality seed. This requires careful collection, processing, and storage. Investing in quality seed will save money and frustration in the nursery and in the field.

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