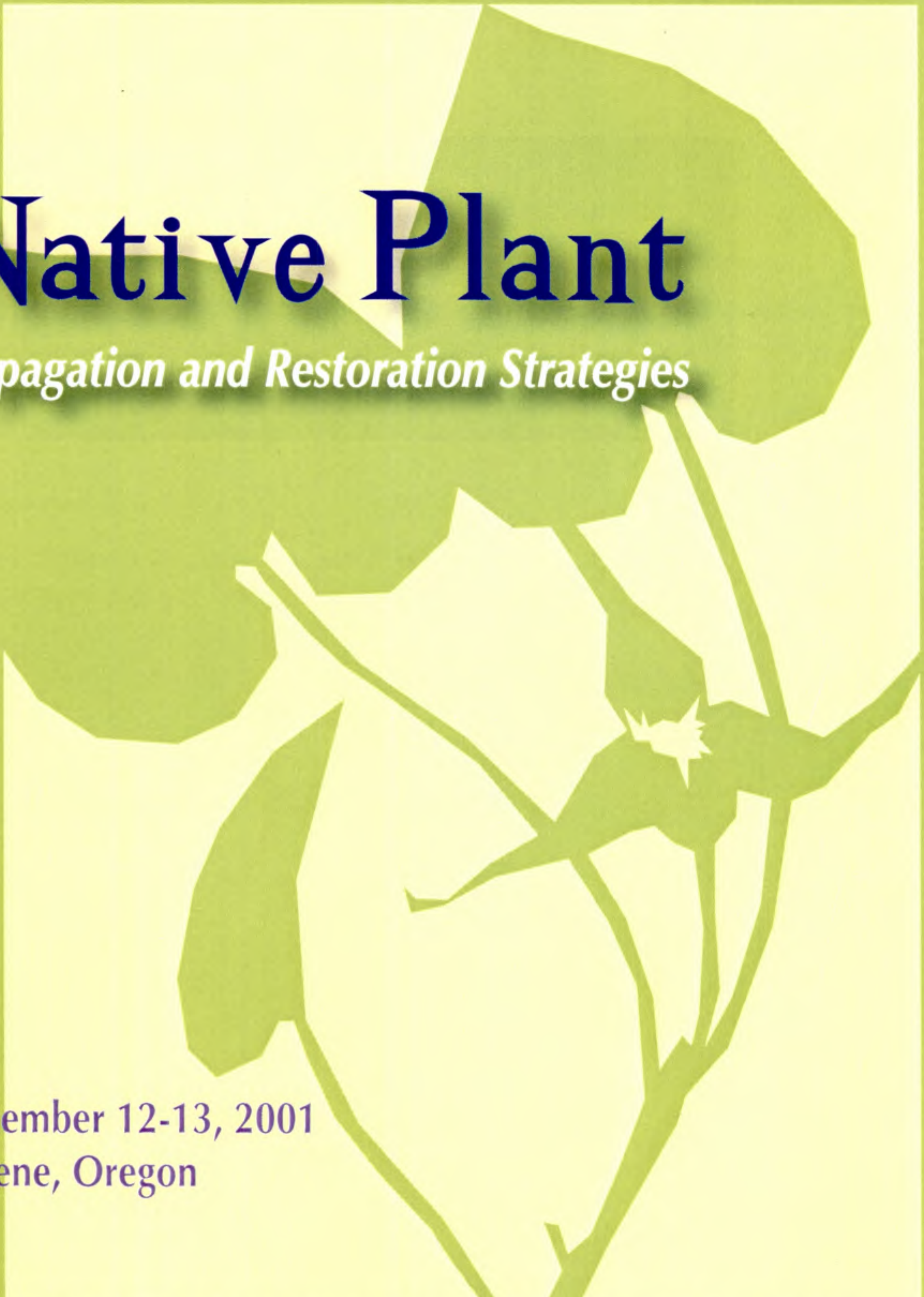
# Native Plant

## *Propagation and Restoration Strategies*



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# Native Plant Propagation and Restoration Strategies

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Editors

Diane L. Haase & Robin Rose

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## Keynote

# Common Ground and Controversy in Native Plant Restoration: the SOMS Debate, Source Distance, Plant Selections, and a Restoration-Oriented Definition of Native

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## Abstract

Propagation and planting of native plants for habitat restoration is a multi-faceted process. There are many issues over which there is general agreement among restorationists, but there are a number of subjects that cause disagreement. For example, restorationists often agree that native plants should be emphasized, but disagree over where seeds or transplants should come from. In this paper, I examine four areas of controversy: the use single or multiple sources of a species at a given restoration site (the SOMS debate), source distance of plant materials, the use of native plant selections, and the importance of one's definition of "native plant." I conclude that some of these issues may be resolved through careful research, while others will remain a matter of personal opinion, and can only be resolved through a clear statement and scope of objectives of each restoration project.

## Introduction

Native plant propagation, restoration, and conservation are complex activities that require many steps and decisions, and face many challenges. On one hand, there is broad agreement, at least among restorationists, over the importance of native plants and the benefits of habitat restoration. But on the other, there is widespread uncertainty and dissent about how to achieve these restoration goals. What should be planted and where? How should plant-materials for restoration be obtained? Where should they come from? What is the overall goal? The objective of this paper is to identify areas of agreement and disagreement to help frame debates in

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native plant restoration, and thus improve our ability to discuss and conduct this work from a position of mutual understanding and productive dialog.

## Areas of Agreement

There is little dispute that native plants are an appropriate choice for habitat restoration projects. Native vegetation provides habitat for the native plants themselves and a vast diversity of other organisms, from wildlife to below-ground soil bacteria, and from common to endangered species. Native plants perform valuable ecosystem functions, such as soil erosion control, nutrient capture, and shade in riparian areas, all of which improve water quality. Healthy plant communities also provide storm water retention and browse for large wildlife. Spring wildflowers in forests retain nutrients released into the soil by tree leaf decay, thus holding these nutrients on-site, making the forest more productive (Risser 1998). Native plants often have unique associations with native insects, providing insect adults with food from nectar and pollen, as well as to larvae from their leaves and other tissues.

There are also several aspects of the restoration process on which most conservationists agree. For example, it is important to set clear, achievable restoration goals. Also, restorationists will be most effective if we document and share all steps of the restoration process and follow-up with monitoring so that we can learn from our successes and failures. We tend to agree that noxious weeds are an impediment to establishing native plants and conserving endangered species. Many of us also recognize that a restoration project is not over once the initial work is completed — restored habitat may need to be monitored and maintained indefinitely by appropriate management. Finally, the economics of using natives are incentives that many restorationists advocate: native species may require fewer resources to maintain (e.g., less water, fertilizer, and mowing) than non-natives, and the commercial propagation of native plants offers a new market for seed growers and nurseries.

But there are important disagreements in the field of native plant restoration. Many of these can be resolved through experimentation and communication. However, some are based on a difference of perspective or goals, and it will be important for the development of our field to articulate these issues and distinguish between technical and the philosophical concerns.

## Controversies

Among the many controversial topics faced by restorationists are issues such as target habitat-type (what plant community should be established?); invasive weed control (what techniques should we use: herbicides, biocontrol agents, soil-scraping, fire, solarization, mowing?); planting material type and technique (direct seeding vs. out-planting of greenhouse starts); the importance of mycorrhizae, *Rhiobium* , and soil food webs; target population size (how big must a restored population be to minimize potentially hazardous stochastic processes?); endangered species (avoiding "take," habitat conservation vs. reintroduction); and cultivation of plant materials (how can different sources be grown at the same nursery and still be considered separate?).

Below I address a few controversies surrounding sources of native plant materials for restoration, such as should single or multiple sources of a given species be planted at a given restoration site? How far should plant materials be moved? Are native plant selections appropriate? And finally, what is a native species?

### Single or multiple source: the SOMS debate

A contentious issue in conservation biology today is whether or not seed sources should be mixed at a restoration site. The SOMS debate, for Single Or Multiple Source, is an argument between those who advocate using plant materials from a single source population and those who favor (or tolerate) mixing materials from more than one source population.

This controversy is as important today as the 1970's controversy over whether to have single large or several small nature reserves (the so called SLOSS debate, see Diamond 1975, Terborgh 1976, and Simberloff and Abele 1976). Genetic principles behind both sides of the SOMS debate are the concepts of inbreeding and outbreeding depression (see Box 1 for a review of these subjects).

Keeping every seed source strictly separate and never allowing mixing or gene flow mimics habitat fragmentation and population isolation, factors that lead to genetic problems including inbreeding depression, drift, reduced diversity, and reduced effective population size. Put another way, it may be possible to be too strict about keeping gene pools separate. On the other hand, mixing sources of plant materials may involve the combination of plants from widely different geographic regions and habitats, and could lead to outbreeding depression (Box I) and the loss of unique genetic qualities of individual populations. An advantage of using multiple sources is an increased likelihood that at least some of the plant materials will be successful at a given site, and mixing may be recommended when seed sources are derived from small, fragmented population.

## Source distance

A related controversy is over the distance plant materials may be moved from source to restoration site. One side of this debate contends that plant materials should be brought only from the closest, most ecologically and/or genetically similar site, while the other argues for the free movement of plant materials from distant sources, as long as the species is native.

Allowing seeds to be moved from distant locations may make more plant materials available at a lower cost than local materials. Acquiring seeds may be much easier, and restoration may therefore be possible at more sites and larger scales.

Keeping sources local may make costs higher, but it improves the chance that the plants will be locally adapted with a "home-site advantage" (Montalvo and Ellstrand 2000b; see Box 2 for a discussion of local adaptation), and therefore may increase restoration success. In addition, local sources reduce the risk of outbreeding depression from crosses between the restored population and neighboring wild populations. Such crosses can also result in hybridization and/or introgression between ecotypes, subspecies, or species, with subsequent risks of local population decline or extinction (Rhymer and Simberloff 1996, Allendorf et al. 2001), and direct threats to endangered species (Levin et al. 1996).

## Plant selections

Selections of native plants are often used for large-scale restoration projects. Plant selections are usually made from a large group of wild collections that are screened for desirable size, survival, and fecundity, then released to growers for commercial production.

For example, researchers at the Agricultural Research Service recently developed hardy natives for rangeland restoration (Dedrick 2000). Their selection and release procedure illustrates the process well. For example, they grew collections of squirreltail *(Elymus clymoides)* from seven western states in common gardens for three years to compare plant growth and seed production (Wood 2000). They selected one strain of this perennial grass for its consistent high-yield of seeds and large size, and released it to growers under the name "Sand Hollow" squirreltail.

This selection has several beneficial qualities. Its superior ability to produce large amounts of seed makes it a good choice for growers, who can generate large amounts of economical seed for restoration projects. Sand Hollow's ability to grow well in many arid environments, tolerate fire, and successfully compete with western weeds, such as cheatgrass *(Bromus tectorum),* make it a good choice in areas where wildfires have damaged sagebrush communities and favored invasive plants, and it may improve habitat for small rodents on which large birds of prey depend (Wood 2000). Since cost savings and high rates of establishment and growth are important to the success of any restoration, vigorous selections are an attractive choice of plant materials.

The arguments against this approach are numerous, however. Since the use of selections often represents a long-distance translocation, selections may not always do well in a given restoration site, especially if that site differs from the selection's original habitat (another example the home-site advantage hypothesis). Further, they may interbreed with local populations of the same species, with the potential for outbreeding depression in their progeny both on the restoration site and in adjacent wild populations.

Selections may also have lower genetic variability than most wild-collected material, potentially making them less able to adapt to a changing environment. And finally, native plant selections may be only a step behind horticultural varieties in their human-induced divergence from wild strains, in some cases making them "quasi-native species," at best. Put another way, they are the product of human selection rather than natural selection, which raises the question, can they still be considered native?

### What is native?

These controversies each have aspects that may be resolved through study of a given species (as in Boxes I and 2), but they also point to the importance of one's philosophical perspective, not the least of which is one's definition of native. A broad definition of native is "indigenous, originating in a certain place." But the goals of restorationists may need a more specific definition when deciding which species will be appropriate for planting in any given area. Wilson et al. (1991) suggested that an ecological definition of native should include consideration for a species' presence in an area prior to Euro-American settlement, its geographical patterns of genetic variation, and its preferred habitat. For example, a population of a native species might be considered non-native for restoration purposes if it represented a genotype not found in that area and/or occurred in a different habitat from the restoration site (i.e., one would not plant a wetland species on an upland site, even if the species was native to the region).

A restoration-oriented definition of native could take this form:

> *A species occurring in an area since pre-settlement times that is adapted to the local ecosystem and is sufficiently like adjacent conspecific populations that, if crossed with them, would produce healthy progeny similar to them in genetic composition.*

The phrase "genetic composition" is intended to mean that the progeny resemble the local parental allelic content and diversity.

Although a narrow definition of native goes to the core of the debates outlined above, it is also not universally accepted. Even so, the identification of genetic and ecological boundaries within a given species, subspecies, or variety has been widely discussed, and even implemented by government agencies. In forestry, "seed collection zones" that recognize these issues have been used to guide tree-seed transfer policies in the U.S. since 1939 (McCall 1939), and there is substantial interest in expanding such policies to all plants (Montalvo and Ellstrand 2000).

Alternative approaches to identifying suitable plant materials include keeping seeds within an ecoregion or subecoregion (e.g., Omernik 1996, McMahon et al. 2001), watershed, county, or some set distance from a restoration site. Such a simplistic approach could be efficient, but will ignore the fact that each species is different and may need a unique zone. Genetic units of conservation, such as Evolutionarily Significant Units (proposed by Ryder [1986]), could be developed for individual plants, but the current cost of this type of analysis will limit its application to a few high-priority species.

## Conclusion: the Importance of Project Objectives

In the mean time, one's position on debates such as those discussed here will depend on the results of careful research projects, opinion, and (hopefully), a large dose of common sense. The goals and funding of an individual project will also influence decisions about issues such as whether or not to use a native plant selection, and how far to transport plant materials. For example, if funding is extremely limited and the goal of restoration is simply to hold soil in place, a manager may choose to ignore source location or genotype when obtaining plant materials, or even use a non-native plant on a restoration site. But if the intention is to successfully recreate a historic landscape, with functioning plant communities and populations that closely resemble wild ones and continue to evolve as they would, a narrow definition of native, careful interpretation of recent research, and practical attention to the ecology and genetics of source materials will be required.

## Box 1. Inbreeding and outbreeding depression

### Inbreeding depression

Inbreeding depression can occur when close relatives mate (or plants self-fertilize) and their offspring display reduced vigor or fitness. Inbreeding depression is a well-known and studied phenomenon, and often occurs in small, fragmented, or isolated populations, or when mating is frequent between close neighbors (Figure 1). It results when deleterious recessive alleles are paired (creating homozygotes) so that their negative effects are expressed in the progeny. When these genes are not paired (as after outcrossing), they may be masked by a more favorable allele (as a heterozygote), so the progeny function normally. In plants, inbreeding depression can be expressed at any stage in the life cycle, including seed germination, seedling establishment, plant growth rate and survival, flowering, and seed production.

Populations suffering from inbreeding depression can often benefit from outcrossing with individuals in other populations, which may result in higher heterozygosity, improved health of individuals, and greater population viability. This is one factor used to support the use of multiple sources of plant materials in restoration (one side of the SOMS debate).

One recent example of inbreeding depression (Richards 2000) in a weedy perennial plant, white campion *(Silene alba),* showed that isolated populations had high inbreeding depression (in the form of low seed germination success), crosses between related individuals resulted in reduced germination success, and gene-flow was higher between unrelated individuals. This study is important because it demonstrates the potential for a "rescue-effect" for populations experiencing inbreeding depression by intentionally mixing unrelated individuals into such a population.

### Outbreeding depression

Outbreeding depression, which is a reduction in fitness of progeny from distant parents (Figure I), has a much shorter history of study and is less documented and understood than inbreeding depression. In a recent (27 November 2001) search of a scientific literature database (Agricola) spanning 1986 through the present, I found 468 papers on inbreeding depression but only 25 references to outbreeding depression. Even so, this hot topic in genetic and conservation research has been demonstrated in various organisms, including salmon (Gharrett 1999), fruit flies (Aspi 2000), and chimpanzees (Morin et al. 1992). Some animal studies have found a positive effect of outbreeding, however, such as in bats (Rossiter et al. 2001). Among plants it may occur in larkspur (Waser and Price 1991, 1994), skyrocket (Waser et al. 2000), a carnivorous pitcher plant (Sheridan and Karowe 2000), Hawaiian silversword (Friar et al. 2001), a Mediterranean borage (Quilichini et al. 2001), a subshrub (Montalvo and Ellstrand 2001), and an exotic roadside weed (Keller et al. 2000).

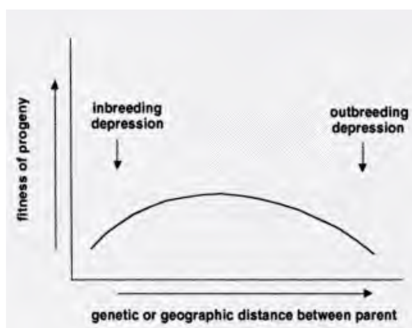


*Figure 1. Inbreeding and outbreeding depression are a function of the distance between parents. Mating between close relatives (or near neighbors) may result in inbreeding depression, while the progeny of genetically distant parents (or organisms from different populations) may cause outbreeding depression.*

In many cases, crossing between unrelated individuals results in progeny with *increased* fitness, followed by the expression of outbreeding depression in later generations. Most researchers (e.g., Lynch 1991, Waser 1993) believe that there is hybrid vigor in the first generation followed by reduced fitness in later generations from loss of ecological adaptation (at least one of the original parents was poorly adapted to the site) and/or disruption of coadapted gene complexes.

One interesting study of outbreeding depression in plants comes from a paper on partridge pea *(Chamaecrista fasciculata,* an annual legume) by Fenster and Galloway (2000). The authors collected plants from various populations ranging from 100 m to 1000 km apart, performed controlled crosses, and grew the parents and progeny in common gardens. They found that first-generation hybrids between plants from different populations outperformed their parents, regardless of the geographic distance between sources. By the third generation, however, this increase in fitness declined. The level of decline varied with distance between parent populations, with crosses between plants from <1000 km apart yielding third-generation plants at least as vigorous as their original parents. Thus, crosses of up to 1000 km had a short-term beneficial effect, and little long-term risk (at least through the third generation).

There have been too few studies of outbreeding depression to make generalizations about the level of risk, however. Other studies have documented negative effects of outbreeding across short distances (tens of meters to 100 m) (Price and Waser 1979, Waser and Price 1989, 1991, 1994) or between different habitats (Montalvo and Ellstrand 2001), while others have found great variability in the effects of outbreeding, even in the same species (e.g., Waser et al. 2000).

The threat of outbreeding depression is one argument against mixing seed sources during plant restoration (another side of the SOMS debate). It is also one of the dangers of moving plants a great distance to a restoration area where they could interbreed with a local population.

### Box 2. The home-site advantage hypothesis

Plants used in restoration are often widespread species, with considerable variation over their geographic range. In many cases, they show ecotypic variation, in which populations differ genetically and individuals from a given environment or region grow better in their home zone than in another region. This has been recognized for tree growth and forest production for many years, even centuries (Langlet 1971), but has not been demonstrated well for shrubs and herbaceous plants. The notion that local plant materials can improve restoration success has been termed the home-site or home-team advantage hypothesis (Figure 2) (e.g., Montalvo and Ellstrand 2000a).

A recent study by Montalvo and Ellstrand (2000b) examined this issue in depth for a native subshrub, California broom *(Lotus scoparius),* in southern California. The authors collected seeds from 11 populations of two taxonomic varieties from three distinct plant associations. They analyzed plants from each population genetically and grew them all together at two of the original collection locations, measuring overall plant fitness (survival x growth) after one year.

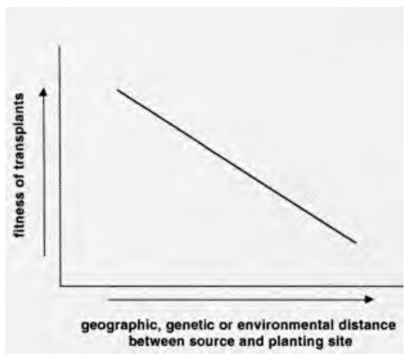


*Figure 2. The home-site advantage hypothesis predicts that individuals from a local site will have higher fitness in their home area than individuals from more distant sources. Montalvo and Ellstrand* (2000b) *found evidence to support this hypothesis in their study of California broom* (Lotus scoparius)*, in which plant performance decreased as the source and home-site diverged environmentally and genetically. Geographic distance of the source was a poor predictor of how well plants performed at the test sites.*

The results indicated strong support for the home-site advantage hypothesis. Geographic distance of the seed source from the out-planting site was a poor predictor of plant performance, but both genetic distance and environmental similarity of the source to the planting site were strongly correlated with plant success. The authors concluded that genetic and environmental similarities of source populations should be considered when source materials are selected for restoration projects.

This study was badly needed and very informative in the debate over how far plant materials should be moved for restoration, but further research is required in this area. In stark contrast to these results is the success of exotic species that can occupy and invade new habitat far from their region of origin, and outcompete the local native species. In addition, some plant selections do well in many habitats over a wide region.

## Acknowledgments

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# Propagation Strategies

## Genetic Considerations for Grassland Restoration in Oregon's Willamette Valley

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Grassland restoration is a management issue, not simply science. Like all management issues, it is a compromise between the desirable and the possible. I learned this on my first restoration project. Yield from local seed collection was tiny compared to the need, so I turned to seed purchases. No commercially available seed was derived from our county, but I considered the sources as acceptable. Commercially available seed included cultivated seed, seed increased for a generation or two from wild sources, and seed collected from the wild — in order of increasing cost. When I calculated how much seed I wanted of each species, the cost was $3200 per acre, more than the entire budget for the ten-acre site. I compromised.

Principles of population genetics should be considered when planning a grassland restoration, but compromise is usually necessary. First, we use these principles to determine what species and seed sources are most desirable, often making those choices despite lack of knowledge about population genetics of individual species. Second, we may compromise to match our desires to real limits of funding, time, and seed availability. Third, we review the plan to assure that it will not harm local stands of native plants and local genetic diversity. Lastly, we finalize the plan, realizing that if we cannot implement an acceptable restoration plan, exotic grasses will grow on the site and competitively exclude native Willamette Valley species.

Conservation biologists and geneticists agree that the best seed sources are wild local populations growing in the same habitats as those found in the restoration site (e.g. Linhart 1993). However, they disagree on how close the sources should be to the restoration site, whether matching microhabitats of source and restoration site is important, and whether using a mix of local and distant sources may be better than using only local sources. Restoration ecologists are interested in the discussion because local wild-collected seed which is carefully matched to individual microhabitats is the most expensive and time-consuming to collect and handle. What is desirable? What is minimally acceptable?

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My answers apply to Oregon's Willamette Valley, where grasslands have been fragmented for only about 160 years. Different rules apply in areas like the Great Basin, where populations may have been isolated for hundreds of thousands of years. My answers are generalizations. When information on genetics of an individual species is available, vegetation managers can craft more precise guidelines.

In this paper, "ecoregion" is defined as a large area with more or less homogeneous climate and vegetation. The ecoregion discussed consists of Oregon's Willamette Valley plus adjacent hills and valleys and part of southwest Washington. "Local populations" grow within I0 or 25 miles of the restoration site.

## 1. Genetic Integrity, Genetic Purity, Genetic Contamination, and Genetic Pollution

These phrases include so many different genetic issues that they are vague. They sound good, though. Use them for influencing decisions, but not for planning. When planning a project, identify the real genetic issues and determine their relevance.

## 2. Outbreeding Depression

This term, while sounding technical, is almost as vague as those above. Offspring that are hybrids between distantly related populations may have poor vigor, reproduce little, or die. The cause may one of the issues discussed below.

## 3. Adaptation/ Maladaptation

Plants from a distant source in a different environment may be poorly adapted to the restoration site. If they are so poorly adapted that they die, money and time are wasted but there is no genetic problem. For example, Idaho Fescue *(Festuca idahoensis* Elmer) is sometimes planted in western Oregon under the mistaken belief that it is native here. In reality, all *F. idahoensis* seed originates east of the Cascades. The species cannot tolerate western Oregon's high fungus populations and seem to need winter dormancy. When planted here, Idaho Fescue dies within a year.

If poorly adapted plants survive to reproduce, their genes may spread among local populations. Natural selection will limit this problem. The severity of the problem depends on the relative size of the introduced and native populations. If the introduced population is relatively small, its genetic impact on surrounding populations will be minimal. However, if the native (local) populations are very small compared to the maladapted introduced populations, maladapted genes could swamp the native genotypes and native populations could be destroyed.

An example of large-scale introduction of maladapted genotypes involves Ponderosa Pine *(Pious ponderosa* Dougl.) occurred in northern Idaho after the massive fires of 1920. Seed was used without regard to origin and no record of the sources was kept. Some stands have grown badly or succumbed to insects or disease. Maladapted genes have shown up in the offspring of more vigorous stands nearby, as well. This Ponderosa Pine example provides an important cautionary tale, but it is unusual because the introduced populations are extremely large compared to the unburned remnant native populations.

Distance between source and restoration sites does not necessarily predict adaptation. For example, showy partridge peas [*Chamaecrista fasciculata* (Muchx.) Greene] grew equally well whether they originated from local populations or from sources up to I000 km away, though plants from 2000 km away grew somewhat worse (Galloway and Fenster 2000).

## 4. Microhabitat Adaptation/ Maladaptation

The genome of a wild plant has been described as "not a fixed homogeneous entity but a deeply fissured, rapidly changing assembly of shapes" (Linhart 1993). Numerous studies have found short-range differences in plant morphology, isozyme profiles, or DNA (review in Linhart 1993). Some of these differences are genetic and clearly adaptive. Extreme differences in adaptation characterize plants living on potentially toxic soils like mine tailings rich in heavy metals, but differences can be found among plants growing on north-facing or south-facing slopes or growing high or low on the slope. Even the relatively uniform environment of Oregon's Willamette Valley presents plants with differences in soil texture, soil chemistry, water availability, temperature, and exposure to light and wind. Local populations often differ genetically and may (or may not) be finely adapted to these small-scale differences.

Individual or population-based variation is not necessarily microhabitat adaptation. It may result from phenotypic plasticity. For example, at Mary's Peak the *Festuca roemeri* growing on rock outcrops has short grayish blue leaves and is more similar to plants of serpentine soils in southwest Oregon than to the tall, blue-green plants of nearby meadows. When they are transplanted to a uniform environment, the differences disappear. If two populations grow in uniform but different environments, this sort of phenotypic plasticity can be mistaken for genetic differentiation among populations. A common garden study, where plants from different sources are grown together, can distinguish the two. Even if genetic differentiation occurs, it may not be adaptive. In *F* roemeri, the difference between hairy and glabrous leaves is genetic. Hairy leaves are very rare in the Willamette Valley. Do the hairy-leaved plants found south of Eugene constitute a distinct ecotype? Possibly, but not probably; glabrous plants inhabit similar habitats. Non-adaptive genetic variation is especially common self-pollinating species such as *Elymus glaucus.* In that species, ecotypes do exist (Snyder 1950) and some isozyme variation is related to habitat (Wilson et al. 2000). However, genetic differentiation has been observed at distances as short as 200 m in apparently uniform habitats (Knapp and Rice 1996), and much of the variation not associated with environment or genetic distance among populations (Knapp and Rice 1996, Wilson et al. 2000).

Although differentiation among local population may result from phenotypic plasticity or individual genetic variation, some is truly adaptive. What is the restoration biologist to do about small-scale adaptive differentiation? One recommendation is to use extremely local seed sources, within 100 m for herbaceous plants and within I km for trees (Linhart 1993). Another is to match source and restoration site habitats carefully. These approaches may be impractical if seed sources meeting these criteria are not available, if money and time are limiting, or if the restoration site includes several microhabitats.

A careful look at differentiation in populations of wild plants suggests an alternative approach. For example, *Veronica peregrina* growing in California's vernal pools are differentiated. Plants growing in the water, near the water's edge, and in nearby grassy areas differ genetically in both isozymes and physiology (Keeler 1978, Linhart 1974, Linhart 1976, Linhart 1988). Restoring a vernal pool thus seems to require collecting and planting V *peregrina* seed in concentric rings around the pool. However, seed dispersal and movement of pollinating insects among the rings must prevent these rings from forming isolated gene pools, suggesting that seed could be mixed and sown throughout a restored pool. This hypothesis is supported because the species survives in a pool that was plowed yearly, stirring the seed bank.

Other studies have found similar patterns at larger scales. The isozymes (genetic markers) associated with plants growing low on a slope occurred on similar microhabitats over large areas in plants as different as Wild Oats *(Avena barbata* Brot.) of California (Hamrick and Allard 1972) and Ponderosa Pine of Colorado (Mitton et al. 1977). This phenomenon provides evidence for microhabitat adaptation, but it also provides evidence for gene flow. The most likely explanation for this pattern is that pollen or seed spread genes more or less uniformly over a large area and then selection imposed the observed microhabitat differentiation. The process can be rapid; Wild Oats has been in California for about 500 years.

If gene flow normally crosses microhabitat boundaries, the restoration ecologist can mimic natural processes by mixing seed from many microhabitats. Using seeds from a variety of locations and microhabitats may insure that at least some of the seeds will grow in each microhabitat in the restoration site (Lesica and Alllendorf 1999). Eventually natural selection will impose a pattern on local population genetics even though seeds were originally planted uniformly

The Meadow Checkermallow *(Sidalcea campestris* Greene) is unusual because plants have different leaf shapes, depending on whether it lives on the east or west side of the Willamette Valley. Obviously genes are not flowing between these two groups of populations. We do not know if this difference is due to chance or related to some adaptation but it is genetic. It seems best to avoid mixing the two forms, at least until more is known about the species.

Before leaving the topic of adaptation, I must comment on misuse of the term "ecotype." We expect outbreeding depression from hybrids between different ecotypes because ecotypes differ genetically in adaptations to different environments. In the native plant business, word "ecotype" is often misapplied to populations that do not differ genetically in traits useful for adaptation. If the restoration ecologist collects bluish, glabrous Roemer's Fescue *[Festuca roemeri* (Pavlick) E. B. Alexeev) from the edge of a grassy bald in Douglas-fir forest in the Coburg Hills east of Eugene, bluish, hairy Roemer's Fescue from oak savannah on a hill top south of Eugene, and green, glabrous Roemer's Fescue from oak savannah low on a slope in Corvallis, has she collected three different ecotypes? Probably not. The differences may be phenotypic, and if they are genetic they may not be markers for different adaptations. (In this example, the differences are genetic, but hybrid vigor, rather than outbreeding depression, characterizes the hybrids; personal observation.) When the restoration ecologist collects from different populations, she has different accessions (collections), which may or may not be different ecotypes. Don't use "ecotype" for "accession."

## 5. Competitive Exclusion

It is theoretically possible for introduced populations of native plants to *be* better adapted to local environmental conditions than local plants of the same species. If so, the introduced lineage will replace local genotypes. Competitive exclusion by non-local native plants is not a serious problem. If microhabitat adaptations are important, local plants should be better adapted than any introduction. Even if species is a habitat generalist, introduced native plants are unlikely to be better adapted than local populations.

The probability of competitive exclusion varies depending on sources and breeding systems. Cultivated strains are the least likely to out-compete conspecific local populations because plants that have been in cultivation for generations tend to become adapted to cultivated fields, not natural ecosystem. Competitive exclusion by a non-local native plant is more likely to occur in self-pollinating or apomictic plants than in outcrossers. In selfers, beneficial mutation A which occurs in one lineage may never meet beneficial mutation B which occurs in another lineage. Therefore, a superior lineage with both mutations A and B is unlikely to form. If such a lineage is introduced, it may be highly competitive. In outcrossing plants, the few beneficial genes from superior plants will spread and mix with local genes, but wholesale extinction of local genotypes will not occur. This might be termed genetic contamination, although it is difficult to consider it a problem.

The competitive exclusion of practical concern for grassland managers occurs when exotic introduced species like Tall Fescue *(Festuca arundinaceous* Schreb.), Colonial Bentgrass *(Agrostis capillaris* L.), and shrubs replace native species. Use of exotics for erosion control, weed suppression, pasture renovation, and other restoration purposes causes competitive exclusion to an extent that use of non-local natives never will.

## 6. Breaking up Co-adapted Gene Complexes

A co-adapted gene complex is a set of alleles which work together to solve a particular environmental challenge. Let's say that in population #1, the alleles that work well together are AA BB CC DD. In population #2, the corresponding alleles are as bb cc dd. If we bring plants from the two populations together, they may produce descendents with various combinations of genes, such as AA bb CC dd, or Aa Bb Cc dd. The combinations (complexes) that did work have been broken up, and the new combinations don't work well. Eventually natural selection will eliminate the descendants with unworkable allele combinations and probably the rarer of the two parental types. In the short term, this can be a problem if the introduced population is large relative to the native one and therefore a high percentage of the progeny have inviable or competitively inferior genotypes.

Breaking up co-adapted gene complexes is unlikely to be an issue for grassland restoration in the Willamette Valley because evolution of different, incompatible co-adapted gene complexes requires time and genetic isolation. Fragmentation of Willamette Valley grasslands began with white settlement 160 years ago. In the absence of relevant information about the species involved, it is more realistic to assume that Willamette Valley grassland species lack incompatible co-adapted gene complexes.

Note that plants isolated since the glaciers retreated 15,000 years ago, like the two Oregon populations of the sedge *Carex macrohaeta*, may have had time to form different, incompatible co-adapted gene complexes. Species isolated for millions of years on the mountain ranges of the Great Basin have certainly had time (though they may not have incompatible complexes). The potential importance of this genetic issue depends on local history.

## 7. Loss of Genetic Diversity

Most wild populations are genetically diverse. Within the overall genetic uniformity of a species, each local population may have its own allele frequencies, rare alleles, or linkage groups. These characteristics can be preserved and, to some extent, spread if each revegetation project uses only local seed sources.

Wherever possible, multiple sources should be used. This helps preserve genetic diversity because many remaining populations of native grassland species are small, disturbed, and vulnerable to extirpation. Using many of these remnant stands as seed sources in each revegetation project creates "back-up" populations that are reserves for these genes. It also permits creation of new gene combinations, perhaps replacing combinations that have been lost.

Using many of the small populations in a restoration project also permits creation of new gene combinations, perhaps replacing combinations that have been lost. No one population of a rare plant contains all the genes that were present in the species before white settlement. Each population has, at most, the genes its ancestors did when the population became isolated (founder effect). Each small, isolated population may have lost genes by chance (genetic drift). Grassland remnants are often in extreme habitats unsuitable for cultivation — rock outcrops, steep slopes, wetlands, and soils with unusual proportions of elements where selection pressures may cause loss of genes for adaptation to mesic sites. However, many of our restoration sites have mesic environments. Recovering the best combination of genes for survival on mesic sites may require plants from many different grassland remnants.

Often local seed sources cannot provide enough wild seed for a project. Therefore, seed may be increased in cultivation. To minimize loss of genetic diversity and maintain necessary adaptations, seed increase should be done for few generations. Cultivation should be done in an area near the restoration site and in similar habitat.

Although seed increase for a few cultivated generations is an accepted practice for virtually all restoration projects, use of selected cultivars of native plant species is more controversial. It is possible for cultivars to become so adapted to cultivated fields that they are unable to survive in the wild, although this is rare with the native species of interest for restoration because are breeders usually select for good initial establishment in the wild. Selected cultivars are much less variable that wild populations. Therefore, using one cultivated source over a wide area does not directly help preserve local genetic diversity, although it is unlikely to harm local genetic diversity as long as local populations are undisturbed. Use of cultivated natives may aid preservation of genetic diversity indirectly by reducing competitive exclusion by introduced exotic species.

Cultivated seed has advantages. It is usually far less expensive than wild-collected seed and is more reliably available in large quantity. The decision to use it must be made in light of the projects goals and resources. If preserving local diversity is a goal, local seed sources should be used, perhaps supplemented with locally cultivated plants. If stopping soil erosion is the goal, a cultivar is perfectly acceptable, provided it originated in the ecoregion and is sufficiently well adapted to the restoration site habitat to grow there.

Vegetation managers occasionally want to know if a given rare species retains enough genetic variation to cope with environmental change. This question assumes that biologists can assess how much variation the species will need in the future, and that if the plant does not meet some standard of genetic diversity, it is unsalvageable. More genetic variation is better than less, but certain plants thrive with very little. Rarity itself is not a reliable predictor of genetic variation (Gitzendanner and Soltis 2000), but aquatic and wetland plants, long-isolated small populations, recently evolved rare plants, and high polyploid hybrids are often invariant or nearly so. Low genetic variation may cause inbreeding depression in a plant that recently lost variation, but low genetic variation in itself is not a predictor of population decline or extinction.

## 8. Inbreeding Depression

In the concern about genetic integrity and genetic contamination, the issue of inbreeding depression is likely to be ignored. Inbreeding is a decrease in vigor, survival, or reproduction in offspring of closely related parents. It may result from the pairing of rare, recessive, harmful alleles or from a general loss of heterozygosity.

The importance of inbreeding depression is probably underestimated for Willamette Valley grassland species. Populations below fifty are often considered safe from inbreeding depression, but grassland populations may be lower than that. For example, one remnant population of Roemer's Fescue consists of thirteen individuals (pers. obs.) Also, the degree of inbreeding depends on the effective population size. The effective population size is lower than the number of individuals present, and reflects the number of individuals that fail to set seed, individual differences in seed yield, and yearly fluctuations in reproductive success.

Harmful effects of inbreeding may be subtle. It may go unnoticed except for hybrid vigor in plants produced in crosses. For example, wild-collected Roemer 's Fescue produces healthy plants in cultivation, but the F I hybrids among different Willamette Valley populations are larger, more vigorous plants with many more seed heads (pers. obs.)

Inbreeding depression is most likely to be a problem for outcrossing native plants that were common and widespread until recently. It is irrelevant to self-pollinating or asexual plants. It is no longer an issue for very small populations that have survived as tiny isolated populations for thousands of years; they have lost their harmful alleles.

Inbreeding depression is not likely to result from the restoration process itself. If the species becomes established at the restoration site, its population will increase quickly and few alleles will be lost. If several well-chosen seed sources were used, the restored populations will experience hybrid vigor rather than inbreeding depression. Although hybrid vigor is greatest in the first hybrid generation, it declines slowly and will be a characteristic of the restored population for many generations.

## 9. Historic Patterns of Gene Flow

Gene flow is the movement of alleles (genes) within and among populations. In plants it occurs mainly through the dispersal of seeds and pollen. Asexual propagation though bulbils, rhizomes, and other fragments is important in some species. Gene flow is important for restoration ecologists for two reasons. First, one of the goals of habitat restoration is, or should be, reestablishing historical patterns of gene flow or compensating for their loss. Second, historical patterns of gene flow delineate the boundaries for seed transfer zones.

Brushy *fence* lines, strips of riparian forest, and greenways function as wildlife corridors, allow raccoons, deer, and other wild animals to travel between populations. No such corridors are available for grassland plants in the Willamette Valley. Roadsides could perform this function, but they are normally planted to exotic species (Tall Fescue, Colonial Bentgrass, etc.) and these species competitively exclude native species. Restoration sites may never fully connect natural grassland remnants, but their restored plant communities can compensate for the loss of gene flow by mixing alleles from different populations.

Although we cannot measure presettlement gene flow, we can make some rough estimates of its extent by observing the forces that spread seeds, pollen, and other propagules through the Willamette Valley and adjacent areas now. Most seeds and pollen grains move short distances but a few move much further. Rare but regular gene movement can knit plant populations together across a wide area, creating one extended gene pool or metapopulation.

Primary seed dispersal is movement of the seed from the mother plant to its first resting place in the soil. Fruit adaptations for primary seed dispersal include hooks that stick seeds to fur or clothing, parachutes for traveling by wind, brightly colored berries that are eaten and cause birds to deposit seeds in their feces, and corky layers that cause seeds to float. Wind-dispersed seeds can cover long distances, floating seeds can move downstream for miles, and animals dispersed seeds may travel as far as their host moves in the day or so it takes the seed to leave the animals. However, many grassland plants have no special adaptation for long-distance seed dispersal. Their primary seed dispersal consists of a fall from the parent plant to a spot a few inches or feet away. Such plants depend heavily on secondary seed dispersal. Secondary seed dispersal is movement from the place where the seed lands to the place where it germinates. Secondary seed dispersal via automobiles and ships is extremely effective. Secondary seed dispersal was doubtless less extensive but still important in presettlement times.

The swollen Willamette River rafted trees, shrubs, tangles of roots, and no doubt seeds downstream during 1996. The great flood of 1861 was of similar magnitude but was not controlled by dams. It flooded the Willamette Valley from the base of the Coast Range foothills on the east to the base of the Coburg Ridge and other foothills on the west. It moved human artifacts from Eugene to Portland and beyond. That hundred-year flood must have moved seeds and other plant propagules mainly downstream but also from side to side in the river's great braided channel. Water's effectiveness at moving upland plants may be demonstrated by collections of *Carex mops,* an upland Cascade Range species, from terraces of the Willamette River near Salem, Oregon (herbarium specimens at the Willamette University Herbarium (WILLU). Extensive flooding is a rare but regular event, but every year rain, streams, and small floods contribute to seed dispersal.

In general, floods disperse seeds downstream, but some 17,000 to 15,000 years ago, floodwaters moved plant parts (along with icebergs, boulders, and silt) south (what is now upstream) in the Willamette Valley. These great Bretz floods were produced by the breakup of glacial dams as glaciers retreated from the Clark Fork of the Columbia River in Idaho. Although they occurred too long ago to affect current patterns of gene flow and genetic differentiation, they are important because they thoroughly mixed seeds from the lower elevations of the entire Willamette Valley ecoregion.

The importance of secondary seed dispersal in mud on humans and other animals has been discovered repeatedly for over a century, and as often ignored. Ungulates are particularly effective for this method of seed dispersal because mud and plant debris collects between their paired hooves. For example, for at least three generations the Wilson family killed all weedy Common Sunflowers (*Helianthus animus* L.) on the family farm in Iowa. Nonetheless, a few Common Sunflowers grew on the farm each year, up to half a mile from the nearest seed source. How did they get there? Their location was a clue; most grew up near deer trails. Dispersal by ungulates like *deer* and elk is particularly important to Willamette Valley grasslands because it may cover long distances uphill and across the divides between watersheds.

The role of Native Americans in plant dispersal has probably been underestimated. Native Americans managed Willamette Valley vegetation intensively by burning grasslands and oak savannas (Johannessen et al. 1970), weeding camas meadows, and controlling competition around preferred plants. Doubtless they dispersed some preferred species over long distances and across watershed boundaries. The sedge *Carex barbarae* may provide an example. Native Americans cultivated *C. barbarae* beds to encourage production of long, unbranched rhizomes and traded the processed rhizomes, which were prized for basketry. They probably transported live rhizomes across the Rogue/Umpqua divide to establish populations on the Umpqua River.

In addition, pre-settlement Native Americans must have dispersed seed unintentionally in all the ways familiar to modern botanists; accidental loss of desirable seed, contamination in bulk seed collections, seeds imbedded in baskets and clothing, seeds stuck in mud on clothes and skin, and little packets of miscellaneous seeds or bulbs transported by children. What is particularly important for our purposes is that Native Americans crossed ecosystem and watershed boundaries. Each year, some individuals traveled the length and width of the Willamette Valley for purposes of trade, ceremony, family meetings, and hunting. Seeds traveled with them.

Pollen dispersal is another form of gene flow. Neighborhood sizes calculated from measured pollen flow can be small; those for *Viola rostrata* are approximately 25 $m^2$ (Levin 1986). However, pollen may travel far enough to affect population genetics. Therefore, recommended isolation distances for research fields of crop plants vary from 300 m to 1.6 km, depending on the pollination mechanism (Briggs and Knowles 1967). On our Iowa farm hybridization occurred between planted Sudan Grass [*Sorghum bicolor* (L.) Moench)] and a population of weedy conspecific Shattercane three quarters of a mile away (pers. obs.).

In animal-pollinated plants, pollen movement depends on how far the animals travel. Most pollinating insects spread pollen only several yards. Hummingbirds can be vectors for long-distance pollen dispersal, especially for plants that flower during migration. Butterflies are not considered efficient pollinators because they often move between different species, but swallowtails, large sulfurs, and most brushfoots can be important agents of long distance pollen dispersal because of a mating system called hilltopping. The males all fly to the tops of nearby hills (feeding and pollinating on the way up) and fly about there, waiting for females. Females fly to the hilltops, mate, and fly back down to lay eggs (feeding and pollinating on the whole round trip). This behavior mixes genes between plants of the valley floor and surrounding hills.

Regular gene flow across half a mile, three quarters of a mile, or a mile makes us look beyond the boundaries of microhabitats and tiny prairie remnant to find seed sources, but it is small compared to the extent of the Willamette Valley. However, these movements were cumulative, spread in all directions, and were interspersed with rare, very long range dispersal.

## Conclusions

Gene flow slowly knitted together the populations of grassland species. It tied together conspecific plants of the Willamette Valley, adjacent hills, larger adjacent valleys, and a bit of southwest Washington into one large gene pool. Therefore, sites in this entire ecoregion can be considered appropriate seed sources for habitat restoration throughout the region.

This Willamette Valley ecoregion does not include the coast, where plants are often adapted to strong wind and salt spray, nor does it include high elevation sites where plants are dormant in winter and bloom much later in summet than plants of the valley floor. Botanists dispute whether this ecoregion includes all grasslands between the Umpqua River and southern British Columbia. During the climate fluctuations that accompanied retreat of the glaciers, the flora moved around this entire area in complex patterns not entirely understood. For Willamette Valley grassland restorations, it is probably best to avoid seed sources south of the Calapooia Divide or north of southern Washington, except in special cases such as Golden Paintbrush (*Castelleja levisecta* Greenm.), extirpated from Oregon but surviving in northwest Washington

Using multiple seed sources is strongly recommended. This helps preserve genes from all the sources used, reverses possible inbreeding depression, compensates for loss of gene flow, and provides a type of insurance in case microhabitat adaptation will prevent seed from some populations from growing at the restoration site.

Choice of seed sources should be based in part on genetic principles. The importance of these genetic considerations varies with the breeding system and abundance of the species involved, with the history of the natural populations in the area, and the type of restoration project.

For self-pollinating and asexual plants (including those that set seed without fertilization), outbreeding depression, inbreeding depression, and the breakup of co-adapted gene complexes are irrelevant concerns. Populations are greatly differentiated genetically, but this is more likely to be due to individual and family differentiation than to microadaptation. Plants with mixed mating systems and outcrossing plants with very limited gene flow are likely to have genetically differentiated populations and are the most likely to be finely adapted to microhabitat differences. Common outcrossing plants with long-distance gene flow are vulnerable to inbreeding depression after populations become fragmented and reduced. They may have microhabitat adaptations that are maintained by selection, but are unlikely to have incompatible co-adapted gene complexes.

Great population differentiation, microhabitat adaptation, and sometimes incompatible co-adapted gene complexes are expected in plant populations that have been isolated for many thousands or even hundreds of thousands of years (like those on mountains of the Great Basin). These traits may also be found in plants isolated since the glaciers retreated some 15,000 years ago. They are unlikely in the Willamette Valley grassland plants that have been isolated for no more than the 160 years since white settlements.

The kind of restoration project done also influences the choice of seed sources. The more sensitive the project, the more important it is to use only local sources. Enhancing an existing native grassland calls for different standards than preventing erosion control on a roadside (Table 1).

Any grassland restoration project is a compromise between the desirable and the possible. It is important to know what is most desirable, but also to be able to choose the best practical alternative. Producing a successful, genetically acceptable restoration is difficult but worth the effort.

**Table 1. Acceptable seed sources for grassland revegetation projects. "Species X" is the species to be planted. "Local seed sources" = the three or four closest populations of Species X. "Area seed sources" = any population in the region of historic gene flow, including cultivated lines derived from area seed sources. The source numbered "1" is preferred to the source numbered "2."**

| Type of project | Acceptable seed sources |
|---|---|
| Natural grassland, Species X present | 1. Seed increase from the site.<br>2. Local seed sources with similar habitat. |
| Natural grassland, Species X absent | 1. Local seed sources.<br>2. Area seed sources |
| Grassland habitat restoration on totally disturbed site. | 1. Local seed sources.<br>2. Area seed sources, including cultivated ones. |
| Revegetation for erosion control. | 1. Area seed sources, including cultivated ones. |

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# Techniques and Considerations for Native Plant Seed Collection

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## Abstract

My first goal is to open a discussion of the ecological, economic and political considerations involved in native seed collection in the western United States at the dawn of the 21st century. My second is to pass on some of the most important practical seed collecting techniques I have developed over the past 18 years. I first discuss ecological impacts of seed collection based on my own observations and propose some simple seed collecting rules. I discuss the economics of native seed collection from a small business perspective. The most dramatic changes in native seed collection may come from political responses to emerging problems, both real and imagined. A recent Forest Service moratorium on the seed collection of five native species is a good example. I propose an alternative approach to current rules and moratoriums.

**Key words**

Rules, Ecological, Economic, Political, Identification, Cleaning, Germination

## Introduction

When I started gathering wildflower and grass seeds in the mountains and deserts of central Idaho almost 20 years ago, I was alone. As far as I could tell, I was the only person professionally collecting native seeds in my area. I wandered around for years. I began the task of identifying all the plants in their dried, seed-producing form. I began to recognize patterns in bloom sequences. I learned how to lengthen my collecting season by moving up and down in elevation.

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Over the years I began to see an increasing interest in native seed collection. The West became the fastest growing area of the country. The demand for native landscapes, especially around trophy homes began to explode. Beautiful color pictures of wildflowers and native grasses began to grace the pages of popular gardening magazines. Federal agencies showed an increased awareness in using native plant materials to combat large-scale devastation due to noxious weeds and wild fires. Cities from Denver, Colorado to Park City, Utah recognized the problems associated with unlimited residential growth combined with finite supplies of water. They embraced xeriscaping and encouraged the use of drought-tolerant, native plants. Native plant nurseries sprouted all over the West. And now, this conference itself becomes evidence of a new level of popularity for native seed collection.

As our young human culture in the West grows and matures, and we continue to learn more intelligent and elegant ways to interface with the natural environment, several ideas become clear. Demand for native seeds continues to outstrip supply for projects and experiments. A nearly unlimited potential supply of native seeds is represented in our millions of acres of public lands. Yet before we unleash masses of new native seed collectors on public or private lands, we need now more than ever to consider the impacts. We need to share our experiences. We need to share our techniques.

## Ecological Considerations

Many years will pass before we have a reasoned and detailed idea of the impact of native seed collection upon our environment. It is part of what I have come to call a "complex biological problem." Even if the impacts of the sustained removal of large quantities of seeds from individual areas are scientifically documented, generalizations to other areas, even short distances away, will be hard to justify. Too many variables exist. However, several observations come to mind as we approach this important problem.

My own experience leads me to believe native seeds can be collected in relatively large quantities without noticeable negative effects to existing plant communities. Generally, most species produce an overwhelming surplus of seeds when compared to the carrying capacity of the surrounding environment. This is especially true in the arid west. The amount of biomass removed is relatively insignificant. Even in the most well-timed and efficient seed collecting operations, most seeds spill to the ground or fly into the air before they can be collected.

The impact of native *seed* collection on animal communities needs to be taken into consideration. Documentation about animal survival dependent upon different seed crops needs to be collected and published for the native seed collecting community.

In my experience, the benefits of collecting native seeds close to where they are planted outweighs the possible negative consequences. We have seen our most successful projects result from native seed collection on or near the project site. With millions of acres of disturbed public lands in the West in need of long-term management for ecological health, reconsidering all areas for careful, controlled native seed collection may be necessary. Many wilderness areas, wildlife refuges, research natural areas and national parks are off limits to native seed collecting. Yet these areas may represent some of the only sources for needed native seed supplies. In addition, many areas off limits to seed collecting are still being grazed by cows and sheep. In these cases, seeds can be harvested with little or no additional impact. New grazing rules could allow both seed collecting and grazing to be optimized.

### Seed collecting rules

Seed collection, especially in sensitive areas as proposed above should not be done without rules. I am sure much discussion will take place before detailed rules are developed and widely accepted. Over the years, I developed a few of my own seed collecting rules.

#### Collect the seeds from no more than one-third of the plants in a population.

If only a few plants grow in a given area, don't take more than one-third of the seeds from any one plant.

### Never disturb single displays or plants identified as sensitive or endangered.

If you are unsure of a plant's status, check with the nearest native plant society.

### Always get the permission of the landowner, public or private.

Emphasize your interest in sustainable seed collection.

## Economic Considerations

As the West runs out of water in relation to its swelling human population, and environmental awareness continues to expand, drought-tolerant, native landscaping itself represents a potentially new multi-million dollar industry. Coupled with increased government agency interest in the use of native plant materials on public lands, native seed collection is sure to be on the verge of economic explosion.

The native seed collecting community should continually question how this industry develops. If the economic practice of native seed collection is to be truly sustainable and environmentally sensitive, it should remain in the hands of relatively small, independent, regionally located businesses, exchanges and agencies. Ecological diversity dictates this. The most elegant model is one with each area having its own small seed company, seed exchange or seed agency supplying seeds, knowledge and rules adapted to each individual region. Paul Hawkin summarized this once when he said:

"You can't run elegant systems from command central."

Unfortunately, our current economic system rewards economic size at the expense of local environments. And many times our federal and state agencies default to practices and contracts favoring larger entities. I suspect those involved in this community of native seed collectors, and I strongly recommend we call ourselves a community, are at least a bit more environmentally sensitive than most. We should unite and use all the new tools to try to create a new economic and environmental model for this industry. Shared on-line seed exchanges and coops should be explored. A sustainable seed trade association was discussed a few years ago at the Eco Farm conference in California and needs to be created. Most of all, we should be aware of the fact that we will all have to work hard, together, if we want this to be a healthy industry. We must not forget what the status quo will bring.

## Political Considerations

The most dramatic changes still to come in native seed collection may be political. The federal government's plan to charge "wholesale market value" for seeds collected on public lands and the recent moratorium on the collection of certain plants needs to be discussed in terms of an overall plan to provide enough seed and promote a sustainable new industry.

As part of a congressional move to find new funding sources for our public lands, the Forest Service has recently been allowed to create a *fee* system for a new category called "special forest products". Botanists in region 4 and 5 are now drawing up plans to allow local ranger districts to implement rules and charge fees for the professional collection of forest materials like seeds and mushrooms. Variation in rules among the different districts is a healthy development, but unless experienced local seed collectors get involved in the process in each district, the rules and prices adopted will not always be intelligent. Now is the time for us all to get to know our local forest ranger.

Because of a perceived threat last year to 5 different native medicinal plants, a moratorium was implemented in regions 4 and 5 of the US Forest Service. The collection of any part of these plants was banned completely. This approach has problems. In some areas inside regions 4 and 5, these plants were not threatened. And furthermore, the moratorium did not address the careful collection of seeds to allow commercial production of these plants, surly the only way to effectively lessen the pressure to collect them in the first place. Input from local individuals spread throughout the region would make regional rulings like this more difficult.

## Collection Techniques

Native seed collection is not especially mysterious or difficult. Probing, poking, shaking, and crushing unfamiliar dried pods and capsules can lead to new challenges and satisfying successes. With few exceptions all flowers by definition produce seeds that can be harvested. However, collecting them efficiently from each different plant species is a complicated question. Each genera and species represent unique sets of problems. Given the limits of this forum, some approaches and techniques are worth mentioning.

### Identification

Of primary importance to a native seed collector is proper plant identification. Most native seeds are worthless commercially unless they can be properly identified to the species level. Unfortunately for new seed collectors, most flower guides describe and picture plants during flowering stage, long before seeds are mature enough to be collected. I offer the following suggestions.

- Taxonomy guides like *Flora of the Pacific Northwest* and *Intermountain Flora* do contain line drawings of seeds and their containment vessels. If you are going to study before entering the field, look first at the differences at the family level. Generally, plant families have similar seed producing systems. Once you recognize the families, you can proceed to finer distinctions.
- Take trips to seed collecting areas while flowers are blooming and plants are identifiable. Sometimes marking particularly promising stands while in bloom with a piece of string will pay large dividends later when seeds are ready.
- If you stumble across a plant gone to seed that interests you, don't leave it behind just because it can't be identified. Search the immediate area for different members of the same species still flowering-fortunately, this is a common occurrence. In some cases, seeds dried and ready to be collected can be found next to flower buds just beginning to open.
- In the mountains, you'll find wildflower seeds dried and ready to be collected at lower elevations, while the same plant blooms higher up the mountain. A seed collector can, in effect, move back in time by climbing to a higher elevation-and thereby solve the mystery of the plant's identity.
- Another trick used by seed collectors is to look in and around plants to find the previous year's dried stalks and seed pods. Even if the seeds have long since disappeared, important clues can be discovered as to the shape and size of the coming seed capsules.
- If you unable to identify a plant, you can always collect a few seeds and plant them at home. This allows you to observe all the growth stages and identify it at your leisure when it finally blooms.

### Timing

Timing is important for successful wildflower collecting. Generally speaking, seeds must be harvested when ripe or dry. In extreme situations, bountiful quantities of seeds found one day completely disappear the next.

- Observe the sequence in which wildflowers bloom each year. The start date for entire sequences changes each year as spring comes early or late. Once a bloom sequence has begun, flowers bloom in the same order more or less, year after year, allowing predictions for the best seed-collecting time. For example, if lupinus is usually ready for seed collection a week after balsamorihiza, and balsamorihiza blooms two weeks later than usual, lupinus seed collection will be delayed two weeks.
- The window of opportunity for successful seed collection varies widely for different plants. A successful seed collector needs to learn these differences. For example: geranium and arnica flowers can be collected early, even while blooming. The flowers mature later into viable seeds when allowed to dry in a paper bag. Lupinus seeds however, must be collected dry in the pods on the plants in order to be viable. Early collection while the pods are green and flowers persist is a mistake.

### Cleaning

Generally, clean seeds sell for more. Beginners have two choices. They can take the time to collect seeds as clean as possible in the field or learn to clean seeds later. Fortunately, simple, inexpensive seed cleaning equipment is widely available.

- A little extra time taken in the field sometimes saves tremendous amounts of time later when trying to clean seeds. This is especially true when dry *seed* stalks can be bent and literally poured into your bags. Some of my favorites include members of the lily family such as xerophyllum, camassia and calochortus. Aster family seeds with a pappus are almost impossible to separate from chaff once collected. I now take the time to carefully pick the parachutes of ripe arnica, aster and erigeron.
- Cleaning screens offer one of the most simple and inexpensive seed cleaning methods. A set of cleaning screens will have differ in the size of the openings which are used to separate seeds from chaff. The screen number denotes the number of openings that will cover one-inch. A screen is selected with openings just large enough to let seeds drop through without the chaff or as in the case of larger seeds, a screen is selected to allow the chaff to drop through without the seeds. I use screen sizes 10, 12, 16, 20 and 24 purchased at my local hardware store.
- Flailing is the process of fracturing or crushing seed pods in order to free the seeds. This can take the form of everything from simply rubbing mustard pods between your hands to driving over sweet pea vines with a car.
- Winnowing is an ancient technique used to clean seeds-moving air from a fan or breeze is used to separate heavier seeds from lighter chaff.

### Germination testing

The application of Federal and State seed laws to numerous new, untested families, genera and species of native plants is problematic for most state seed labs. Different requirements are emerging from different states, and many states have no requirements for natives. Check with your local state seed lab to see if germination standards have been established for the natives you will be collecting.

Tetrazolium (TZ) testing has emerged as an alternative germination test. This is important for native seeds because it tests for viability without having to break dormancy. The test is allowed in Idaho and some other states and is quite easy to perform on your own. Check with your local seed lab. Tetrazolium is widely available at local pharmacies. Seeds are tested by soaking them, cutting them in half and then applying the TZ. Each living seed stains the TZ blue. You can get a copy of the Tetrazolium Testing Handbook, #99, 1999, from the Association of Official Seed Analysts, aosaoffice@earthlink.net.

### Labeling

As State Seed Labs begin to digest the complexities of native plants for the first time, new labeling procedures are beginning to emerge. Many western states now have an alternative wildland collected site identification tag to substitute for the certified seed tags traditionally used for commercial seed crops. Again, you should check with your state seed lab for exact requirements.

I always keep detailed records about each seed-collecting trip and each seed sample. I carry small zip-lock plastic bags, an indelible-ink pen, and a notebook. I put each seed sample in its own bag and label it with the following information: species name, common name, date; location, elevation, surrounding vegetation, slope angle, soil description, sun exposure, time it took to collect, estimated number of plants in the area and any other relevant comments.

## Conclusion

Collecting native seeds is an amazing, interesting and wondrous activity. If you think for a moment, seeds are living embryos. They represent life in its most diverse, durable and condensed form. Each seed contains countless years of evolutionary feedback as well as instructions for potentially unlimited self-reproduction. Seeds are software and hardware rolled into a package so tight, so efficient and so elegant, nothing we humans have developed comes close.

Our remaining native seed stocks deserve a community of native seed collectors which will share its concerns and techniques, one continually questioning its place in the ecology, economy and community of this fragile world, one that knows we must come together to survive.

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# Some Procedures for Dormancy Break and Germination of Difficult Seeds

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## Abstract

Seeds of a number of species we have studied over the past three decades are difficult to germinate. We have learned how to use information about the habitat and ecological life cycle of a species to plan effective strategies for breaking dormancy and promoting germination, e.g., when to use warm and/or cold stratification treatments. Also, we have become aware that temperature, light, substrate, and flooding (low oxygen) regimes during both the dormancy breaking and germination periods may influence germination percentages of a species. In this paper, some of the precautions and procedures we have discovered that help ensure high percentages of seed germination will be discussed.

### Key words

cold stratification, flooding, light requirement, seed coat permeability, substrate, temperature, warm stratification

## Introduction

Our experience with seeds comes from more than three decades of studies on how timing of germination is controlled in the field. To understand the seed germination ecology of a species, it is necessary to determine if fresh seeds are dormant and if so what kind of dormancy they have, when and how dormancy is broken in

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nature, and what environmental conditions are required for germination of nondormant seeds. In these studies, we have encountered a number of species whose seeds were difficult to germinate. For some species, high germination percentages were obtained when seeds were incubated at temperature (and to some extent soil moisture) regimes occurring in the habitat from the time of seed dispersal until the end of the natural germination season. However, even this approach did not result in high germination percentages in all species; consequently, changes in our experimental protocol for seeds of some species were required. The purpose of this paper is to briefly discuss some of the things we have learned about various species that help ensure high germination percentages.

## Lessons We Have Learned

### Filled seeds

In 1991, we buried approximately 156,000 seeds of Carex *lacustris* under flooded and under nonflooded conditions in a nonheated greenhouse in Lexington, KY. At monthly intervals, seeds from flooded and nonflooded conditions were exhumed and tested under nonflooded conditions in light and in darkness at five day/night alternating temperature regimes. After 7 mo, a grand total of only seven seeds had germinated in all germination tests. At this point, some seeds were cut open, and we discovered that only about I% of them contained an embryo! Thus, we learned the hard way that just because seeds are large and feel firm to the touch both before and after imbibition does not mean they contain an embryo. Checking for presence of an embryo is always a good start for any seed germination study.

### Dormancy break at high temperatures

Although cold stratification [moist, low temperature (about 0 to 10°C ) conditions] breaks seed dormancy in many species, this treatment usually is ineffective in breaking dormancy in seeds of winter annuals and in those of autumn-germinating perennials. The best way to break dormancy in autumn-germinating seeds is exposure them to the temperature conditions of summer; the effective temperature range for dormancy loss is I5-35°C, with 20-30°C being optimal for many species. Cold stratification of autumn-germinating species actually can decrease germination. For example, fresh seeds of the redcedar (limestone) glade endemic

*Delphinium carolinianum* subsp. *calciphilum* germinated to 46 and 55% in light at I0 and 15°C, respectively, but after 2 mo of cold stratification germination was only 5 and I0%, respectively; after 2 mo of dry storage at 20-25°C, seeds germinated to 85 and 29%, respectively (Baskin and Baskin unpubl.). It should be noted, however, that seeds of the mesic woodland species *D. tricorne* require cold stratification for dormancy break (Baskin and Baskin 1994).

One problem in working with seeds that come out of dormancy during summer is deciding what moisture regime to use. Seeds of many winter annuals will come out of dormancy while stored dry at 20-25°C; this is called afterripening. Seeds of the woodland herbaceous perennial *Polemonium reptans* subjected to natural temperatures throughout the summer and watered daily germinated to 91%, while those stored dry at natural temperatures throughout the summer germinated to only 27% (Baskin and Baskin 1992a). (If seeds are moist during exposure to high temperatures, the treatment is called warm stratification.) On the other hand, seeds of the winter annual *Lesquerella filiformis,* a Missouri redcedar glade endemic, kept on continuously-moist sand at simulated summer temperatures (30/15°C day/night regime) for 3 mo did not come out of dormancy. The best moisture regime for dormancy break in seeds of *L. filiformis* was alternate wet (5 days) and dry (I0 days) cycles throughout the summer (Baskin and Baskin 1998, unpubl.).

### Dormancy break at low temperatures

Cold stratification frequently is effective in breaking seed dormancy of spring-germinating species in temperate regions; however, some species require warm followed by cold stratification (see below). Although 5°C often is reported in the literature as being the optimum temperature for cold stratification, it is not the optimum temperature for all species. In fact, 5°C may be too high to break dormancy in seeds of some species. For example, seeds of *Alliaria petiolata* stratified in darkness at 5°C germinated to I, 1, and 0% in darkness at 15/6, 20/10, and 25/15°C , respectively, while those statified in darkness at 1°C germinated to 60, 57, and 51%, respectively, in darkness (Baskin and Baskin 1992b). In *OsmorhiZa occidentalis,* the small (underdeveloped but differentiated) embryo grew while seeds were being cold stratified at 5°C, but seeds failed to germinate. In this species, the optimum temperature for embryo growth, dormancy break , and germination was 1°C (Baskin *et al.* 1995).

### Warm followed by cold stratification

It is well known that warm followed by cold stratification is required to break dormancy in many species whose small (but fully differentiated) embryos also have physiological dormancy, *e.g., Erythronium albidum, Osmorhiza longistylis, Jeffersonia diphylla, Panax ginseng, Ilex opaca,* and *Taxus baccata* (Baskin and Baskin 1998). (In these species, the embryos must become fully elongated inside the seed before the radicle will emerge.) Although *Empetrum bermaphroditum* seeds have fully developed embryos, warm followed by cold stratification also is required to break dormancy in a high percentage of them (Baskin *et al.,* in press). In other species with fully developed embryos, *e.g., Florekea proserpinacoides* (Baskin et al. 1988) and *Cardamine concatenata* (Baskin and Baskin 1994), 12 wk of cold stratification were not effective in breaking dormancy, and 18 wk of cold stratification resulted in only about 50% germination. However, when seeds of *F proserpinacoides* and *C. concatenata* first were warm stratified for 4 wk, 100% of them germinated after 12 and 14 wk of cold stratification, respectively.

### Permeability to water

Sometimes, seeds do not germinate because the seed or fruit coat is impermeable to water, and thus they fail to imbibe (swell) when placed on a moist substrate; this is called physical dormancy. The families known to have taxa with impermeable seed or fruit coats are the Anacardiaceae, Bixaceae, Cannaceae, Cistaceae, Cochlospermaceae, Convolvulaceae, Cucurbitaceae, Dipterocarpaceae, Geraniaceae, Leguminosae, Malvaceae [now also includes the Bombacaceae, Sterculiaceae, and Tiliaceae *(sensu* Bremer *et al.* 1999)], Nelumbonaceae, Rhamnaceae, Sapindaceae, and Sarcolaenaceae (Baskin *et al.* 2000). However, not all taxa in these families have physical dormancy. In fact, some tropical members of the Anacardiaceae, Bombacaceae, Cucurbitaceae, Leguminosae, Malvaceae, Sapindaceae, and Sterculiaceae have recalcitrant seeds, i.e. if seed moisture content declines below 15-45 %, depending on the species, the seed loses viability (Baskin and Baskin 1998). The way to determine if seeds are permeable or impermeable to water is to weigh them before and after they have been on a moist substrate for several hours. An increase in weight indicates that seeds are permeable to water and no increase that they are impermeable.

Some taxa in various families including the Anacardiaceae, Apocynaceae, Arecaceae, Betulaceae, Burseraceae, Caprifoliaceae, Cornaceae, Elaeagnaceae, Empetraceae, Ericaceae, Juglandaceae, Meliaceae, Menispermaceae, Moraceae, Nyssaceae, Oleaceae, Pandaceae, Rhamnaceae, Rosaceae, Sapotaceae, Styracaceae, and Zygophyllaceae have seeds covered by a hard or stony endocarp. However, water-impermeable endocarps in this group of families are known to occur only in *Rhus* and a few of its closely-related genera, in the Anacardiaceae (Baskin and Baskin, unpubl.). In dealing with seeds covered by stony endocarps, one is tempted to scarify them because they feel hard to the touch, but scarification may not improve germination. In fact, scarification could allow pathogenic organisms to invade and destroy the embryo. Thus, before scarifying stony endocarps, it is advisable to first determine if they are impermeable to water. In *Empetrum hermaphroditum* (Empetraceae in the strict sense), seeds are covered by stony endocarps, the endocarp is permeable to water, and a sequence of warm followed by cold stratification treatments is required to break dormancy in a high percentage of the seeds. Thus, warm stratification plays a role in breaking dormancy of the embryo and not in making the endocarp permeable to water, as has been speculated for some seeds with stony endocarps (Baskin *et al.,* in press).

## Substrate effects

In some species, the problem of low germination percentages can be solved by changing the substrate used for seed incubation. Freshly matured seeds of *Campanula americana* germinated to 65, 87, 85, and 44% on soil in light at 15/6, 20/10, 25/15, and 30/15°C, respectively, but to only 5, 29, 76, and 55%, respectively, on sand (Baskin and Baskin 1984). Further, the substrate effect was accentuated following 12 wk of cold stratification in light at 5°C. Cold stratified seeds germinated to 89, 81, 83, and 62% on soil in light at 15/6, 20/10, 25/15, and 30/15°C, respectively, whereas those on sand germinated to only 2, 12, 35, and 39%, respectively (Baskin and Baskin 1984).

Following 16 wk of cold stratification in darkness at 1°C, seeds of *Alliaria petiolata* germinated to 60, 57, 51, and 35% on soil in darkness at 15/6, 20/10, 25/15, and 30/15°C, respectively, but none of those on sand germinated (Baskin and Baskin 1992b).

## Temperatures for seed testing

It is possible to break seed dormancy but not to obtain seedlings because the appropriate conditions for germination were not provided. For example, seeds that have been warm- or cold-stratified may fail to germinate because temperatures are too high or too low, depending on the species. Thus, some species germinate best at low temperatures, others at high temperatures, and still others at intermediate temperatures. Nondormant seeds of the desert winter annual *Eriogonum abertianum* germinated to 86 and 79% in light at 15/6 and 20/10°C, respectively, but to only 3, I, and 0% at 25/15, 30/15, and 35/20°C, respectively (Baskin *et al.* 1993). Nondormant seeds of the herbaceous polycarpic perennial *RueIlia humilis,* on the other hand, germinated to 0 and 15% at 15/6 and 20/10°C, respectively, but to 98, 100, and 1_00% at 25/15, 30/15, and 35/20°C, respectively (Baskin and Baskin 1982). In contrast to both *E. abertianum* and *R. humilis,* nondormant seeds of the winter annual *Chaerophyllum tainturieri* germinated best at an intermediate temperature, *i.e., 7,* 39, 0, and 0% germination at 15/6, 20/10, 30/15, and 35/20°C, respectively, and 99% at 25/15°C (Baskin and Baskin 1990).

Another thing that might be helpful to know is that the temperature range for germination can widen as seeds of many species come out of dormancy. Being aware of this might allow you to obtain seedlings sooner than you would otherwise. For example, as seeds of the summer annual *Bidens polylepis* come out of dormancy during cold stratification, they exhibit a decrease in the minimum temperature at which they will germinate to 50% or more. After 2 months of burial in soil at natural winter temperatures in Lexington, KY, seeds germinated to about 95% at 30/15 and 35/20°C, but germination at 15/6°C did not exceed 50% until after seeds had been buried for 5 mo (Baskin *et al.* 1995). Thus, if we had been using only the 15/6°C temperature regime, we would not have known that seeds of this species are capable of germinating to high percentages after only 2 mo of exposure to winter conditions.

As seeds of the winter annual *Alopecurus carolinianus* come out of dormancy during warm stratification (buried in soil and exposed to summer conditions), they exhibited an increase in the maximum temperature at which they germinate to 50% or more. After I mo of burial, seeds germinated to about 85% in light at I 5/6°C, but germination at 30/15°C did not exceed 50% until after seeds had been buried for 4 mo (Baskin *et al.* 2000). Thus, if we had been using only the 30/15°C temperature regime, we would not have known that seeds of this species are capable of germinating to high percentages after only I mo of exposure to summer conditions.

## Light requirement for germination

Another reason why seeds that have been sufficiently warm and/or cold stratified may not germinate is the lack of appropriate light or dark conditions. Although nondormant seeds of many species germinate equally well in light and darkness, it is not unusual for germination percentages to be higher in light than in darkness. Further, seeds of some species require light for germination, and those of a relatively few species require darkness (see chapter 10 in Baskin and Baskin 1998).

Seeds with an absolute light requirement for germination vary with regard to the time when the light requirement can be fulfilled. Seeds of *Solidago altissima* and *S. nemoralis* exposed to light during a 12-wk cold stratification period at 5°C subsequently germinated 82 and 99%, respectively, in darkness at 20/10°C; seeds cold stratified in darkness and incubated in darkness germinated to 0 and 1%, respectively (Walck *et al.* 1997). Thus, the light requirement could be fulfilled during stratification, and seeds could germinate in darkness at simulated spring temperatures. On the other hand, seeds of Cyprus *squarrosus* (syn: *C. aristatus,* C. *inflexus)* require cold stratification and light for germination, but the light requirement for germination can not be fulfilled during cold stratification. Thus, light is required for germination of nondormant seeds during incubation at suitable spring-summer germination temperatures (Baskin and Baskin 1971). For many species, light during both the dormancy breaking and germination periods results in higher germination percentages than when light is given during only one of the periods, *e.g.,* seeds of *Echinacea angustifolia,* which require cold stratification for germination (Baskin *et al.* 1992).

### Effect of flooding

Although flooding, which results in low oxygen availability, may inhibit dormancy break in some species (Baskin *et al.* 1994), it has no inhibitory effect on dormancy loss in seeds of some wetland species (Baskin *et al.* 1996). However, maximum germination may be obtained in some wetland species by cold-stratifying seeds under nonflooded conditions and then germinating them in light under flooded conditions, *e.g., Schoenoplectus purshianus,* a summer annul occurring on wet mud adjacent to depression flooded during summer (Baskin *et al.* 2000). Thus, for species growing in wet habitats, it is important to determine the time of year when seeds are flooded.

## Conclusions

Some of the difficulties in germinating seeds, especially those for which no previous research data are available, can be avoided by (I) making sure the seeds have an embryo, (2) determining if seeds imbibe water, (3) using a range of test temperature regimes, (4) incubating seeds in both light and darkness, and (5) simulating warm and/or cold stratification treatments and substrate moisture conditions that seeds would be exposed to in the field from dispersal to germination. Thus, the more one knows about the natural habitat and ecological life cycle of the species, the easier it will be for him/her to plan effective strategies to obtain high germination percentages.

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# Forb Seed Production at J. H. Stone Nursery

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## Abstract

J. Herbert Stone Nursery began producing native forb seed in 1996. Nursery seedbeds are established from source-identified wild seed populations collected on public lands. Each collection (seedlot) is maintained separately from other seedlots of the same species to prevent cross-pollination. Sowing, culturing, harvesting and storage practices for seed propagation are discussed.

**Keywords**

Restoration, native plants, federal nurseries, seed propagation, public lands, source-identified seed, forbs

## Introduction

Site-specific, source-identified native seed is important for use in the restoration of public lands. In 1996, we were asked by public land managers to produce site-specific native forb seed for their projects. This was the beginning of the native forb program at J. Herbert Stone Nursery. Although our program is in it's infancy it is our hope that we will be able to provide native forb seed increase opportunities for any interested public land manager in the future. Stone nursery was originally established as a conifer nursery in the late seventies. This began to change in 1991, when Stone Nursery began a native grass seed program in response to the demand of many public land management specialists for site specific, source-identified seed. As we became established in native grass seed production, we began tc receive many requests for native forb seed. For us it was a natural extension of out native grass seed program. We were interested in diversifying nursery products be-

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cause long term needs for conifer seedlings were declining. Over the past six years the forb program has grown and today we have grown over 30 species of fortis. This year we produced 1000 lbs. of forb seed from 2 acres of land.

## Nursery Site Description

Our 3 11-acre nursery is located in Southwestern Oregon several miles west of Medford. We have a long growing season and a dry climate, which appears to be beneficial for forb seed production. Our growing season begins in March as daily temperatures average between 47-57° F. Flowers develop during spring and are ready for harvest from mid May through October depending on the species. Average minimum temperatures from May through October range from 55-75° F, while average maximum temperatures range from 67-92° F. Average annual precipitation is 19 inches, mostly as rainfall. Summers are dry with typically less than 4 inches of rainfall occurring between May and September. Nursery soils are deep and fairly well drained. They are mildly acidic (pH 5.5 to 6.0), sandy loam soils with relatively high fertility levels due to several decades of conifer production.

## Seed Production

Starter seed from wild native populations is collected from specific public forest or range locations. Wild forb seed ripens from early summer to late fall. Dried seed heads, pods etc. are removed from the plant stalks by stripping, cutting or vigorous shaking. These are placed in a paper bag for further ripening and drying. Depending on the need, the collection can be hand cleaned or sent to a seed extractory. Obtaining clean, pure seed is critical for sowing through our machinery and for sowing in the nursery beds. Each collection is maintained as a distinct seedlot with it's own unique identity.

### Seed conditioning

Forb seed conditioning requirements for the species that we have worked with vary widely. Conditioning or stratification can be thought of as treatments that simulate normal environmental conditions to overcome latent dormancy and trigger seed germination. We have used the following conditioning techniques to promote forb seed germination; cold — wet stratification, peat stratification, scarification, sulfuric acid, natural stratification and no stratification. Cold — wet stratification involves soaking seed in water for a period of time followed by cold storage at 3 3° F and high humidity for 30 to 120 days. Peat stratification involves soaking the seed in water, then placing the seed in moist peat that is held at 33° F for 30 to 120 days. Scarification is a mechanical or chemical abrasion of the seed coat usually followed by cold — wet stratification. Natural stratification is simply sowing the seed in the fall and exposing the seed to winter conditions. For some species no seed conditioning is required and seed sown in the fall germinates immediately. Also, it is possible that the process of drying and extraction alone is somehow a form of conditioning. In general, fall sowing and natural stratification appears to be the best strategy for forb germination and plant development.

### Sowing

Seedlots for seed production are sown in the fall on fumigated soil. Phosphorous and potassium are incorporated at rates of 250 to 300 pounds per acre prior to bedforming. We sow the seed on four foot wide raised seedbeds in four bands which are 0.75" deep, 1.25" wide and 12 inches apart with a modified Oyjord seed drill. Packing wheels on the drill press the seeds into the soil. A layer of sawdust just thick enough to cover the seed is then placed on top of the seedbed. Constant moisture is maintained in the seed / soil / sawdust interface with irrigation until the fall rains begin. Most germination takes place within 10 to 21 days after sowing, however some seed germinates over winter.

Target density for seed production is one plant per inch of seed row or 12 plants per square foot of seedbed. Seedlot test information such as the number of seeds per pound, germination percentage, purity and previous field performance are used to determine how many pounds of seed per acre to sow. Unfortunately, most seedlots do not have any tests performed prior to sowing because they are collected late in the season and the amounts are too small to test. Another reason that germ tests are not done is that germination techniques haven't been developed. In these situations, the judgment and experience of the program manager and the seed drill operator are used to determine adequate sowing rates.

Fall is the preferred season for sowing at our site for several reasons. Many species germinate and grow, producing greater yields the following summer than spring-sown seed. Seeds can also be naturally conditioned in situ when sown in the fall. We have found that the cool fall temperatures limit the germination and growth of many of the local weed species and as a result weed competition is reduced. Fall sowing also allows us to spread the nursery workload more evenly throughout the year. Due to soil conditions, ground preparation in the fall is easier to accomplish at our site.

Seedlot locations are selected using a minimum isolation distance of 150 feet between collections of the same species so that the pollination contamination potential is reduced. The isolation distance of 150 feet is based on native grass parameters. So far, we are not experiencing any difficulty finding space for forb plantings.

## Culturing

After germination and seedling emergence, plants grow at minimal rates during the winter. As temperatures begin to rise in mid to late February, forbs respond with increased growth rates. Rapid vegetative growth occurs in March to early April and flowers begin to appear. During this period beds are treated with 3 applications of ammonium nitrate (100 pounds/acre) and plants are irrigated frequently to increase plant vigor and promote seed production. For established older plantings, the early growth period beds are fertilized with 250-300 pounds of triple 13 with trace elements. After seed harvest the remaining stubble is removed with a silage chopper that mulches the material into the tractor paths. Post harvest plants are maintained with minimal irrigations. Early in the fall, irrigations are increased to encourage root growth. One application of ammonium nitrate (100 pounds/acre) is made early in October.

Monitoring for insects, disease and weeds is critical during the rapid growth and flowering period. Forbs have a broad spectrum of pest problems such as rust, smut, thrips and mites. These pests are generally specific to certain species and are usually controlled with cultural or chemical treatments. Because the seedbeds are often in place for several seasons, weed control is the most significant pest problem we encounter. It is a costly, year-round endeavor requiring a wide range of tools. We begin with soil fumigation. While the main reason for fumigation is to eliminate or reduce soil borne pathogens, it also controls seed germination from previous forb or grass crops as well as wind borne weed seed. Cultural methods such as sowing in the fall and establishing and promoting a high-density forb cover can reduce weed populations. However, exposed spaces remain available in tractor paths and beds and are fertile sites for weed to thrive. Weed seed is reduced by controlling weeds in and around nursery fields through mowing and cultivation. Tractor paths are periodically treated by mechanical cultivation or tilling. Herbicides are used to treat paths, pipelines and shoulders of roads. Hand removal of weeds within the beds is our main method of weed control. It is effective but costly, and there is a level of education necessary in order to distinguish between weeds and crop plants.

## Harvesting

Forb species are harvested from mid May to late October. Seed ripening is strongly influenced by the climactic conditions during the early spring and mid summer. Cooler temperatures and higher precipitation will slow *seed* maturation. On our site Ranunculus species ripen first, followed by Plagiobothrys and the lupines. The last forbs to be harvested are Achillea, Spirea and Aster. As the harvest season begins each seedlot is monitored on a weekly basis for seed ripeness. The monitoring process intensifies as each seedlot matures, with routine daily and even hourly evaluation checks. Determination of forb seed maturity is based on embryo development, seed color, ease of removal, seed loss and personal judgment. Most individual plants or even flowers on a plant do not mature at the same time. Judgment is used to set the harvest date to obtain the maximum amount of harvestable seed for each seedlot.

The diversity of forbs grown at the nursery has led to diversity in harvesting methods. Our primary method of forb harvesting is to thresh with a combine. Since most of our forb crops have limited, manageable amounts of vegetation, a combine can easily cut the material and process it through the drum and concave. Seeds are easily dislodged from the pods or seed heads while stems, leaves and other debris are separated out with directed air and sieving.

For crops with a large amount of biomass, we use a swather and then we thresh with a combine. Swathing is the process of cutting the plant and placing it on the surface of the bed to dry. Two to three days after swathing, the plants are processed through a combine. Swathing accomplishes several objectives. Drier plant materials are quicker and easier to process through a combine. Seeds of swathed plants are less likely to be dislodged by wind or rain because the plants are massed or grouped together at the bed surface and protected from storm events. Seed ripening can continue after swathing, which extends the window for harvesting resulting in greater flexibility.

For species with tiny air-borne seeds such as *Microseris lanatum* or *Aster hallii,* a Flail vac seed stripper is used. Stripping utilizes a spinning brush that moves over a crop, pulls the plants in and removes seed. It is mounted to a front loader on a tractor and powered with a hydraulic motor. It is used for plants that aren't compatible with the blowers that accompany the threshing process in a combine. Harvest purity for crops that have been stripped is lower than those that have been threshed because the brushes tend to pull a lot of stems off with the seed.

Another stripping machine that we use is the Native Prarie seed stripper (model 410). This is essentially a self-contained stripping unit that is pulled by a small quad ATV. The operator orients the brush and adjusts the speed and then moves through the bed. We are interested in this method because we think it can be easily used anywhere there are desired forb (or grass) species in relatively pure stands.

Of course we still use the oldest methods of seed harvesting — hand collecting. Early in the forb program we harvested many species by hand until we became familiar with the seed characteristics. Hand harvesting works but it is quite time consuming and costly. This season we hand harvested *Madia sativa* or coast tarweed because it was so sticky that none of our equipment would work. It turned out to be so difficult that we could hardly collect the seed by hand. In this species natural habitat seed is easy to collect because it is low growing. But at the nursery it grew to over 6 feet in height and we could barely move through the bed to pick the seed.

Although we have been growing forb crops for several years we don't have firm harvest yield data. We have seen that the yields vary considerably by species, seedlot, growing season and the age of the seedbed. An additional complication is that several species don't produce seed until the second or even third growing season. Table I shows comparative yields for forb species.

**Table 1. Projected yield (pounds per acre) based on forb plot yields at Stone Nursery**

| Species | Est. Yield |
|---|---|
| *Achillea millifolium* | 340 |
| *Anaphalis margaritacea* | 90 |
| *Aster hallii* | 350 |
| *Astragalus canadensis* | 660 |
| *Beckmania syzigachne* | 500 |
| *Boisduvalia densaflora* | 600 |
| *Downingia elegans* | 220 |
| *Downingia yina* | 180 |
| *Eriogonum racemosum* | 100 |
| *Eriophyllum lanatum* | 300 |
| *Gratiola ebracteata* | 1000 |
| *Grindelia intergifolia* | 380 |
| *Lupinus latifolius* | 200 |
| *Lupinus polyphyllus* | 300 |
| *Lupinus rivularis* | 850 |
| *Lupinus sericeus* | 380 |
| *Madia elegans* | 800 |
| *Madia sativa* | 300 |
| *Microseris laciniata* | 180 |
| *Orthocarpus bracteatus* | 50 |
| *Plagiobothrys figuratus* | 150 |
| *Prunella vulgaris* | 320 |
| *Ranunculus occidentalis* | 120 |
| *Ranunculus orthorhyncus* | 180 |
| *Spirea betulifolia* | 170 |
| *Stachys mexicana* | 160 |
| *Wyethia angustifolia* | 320 |

## Seed processing and storage

After a seedlot is harvested it is placed in a drying bin. The bottoms of these drying bins have fine mesh screen on the bottom to keep the seed in but allow air passage. Bins are stacked six high over a plenum. Warm air (100° F) is blown into the plenum and up through the seed bins. After 12 hours of drying, seed samples are removed from the bins and the moisture content is measured with a Mettler moisture analyzer or with oven drying. Oven drying requires at least 4 hours while the Mettler test takes only 5 to 8 minutes. When the moisture content is between 5 to 8% the bin is taken off the stack and the seed is packaged. Dried seed is placed in plastic bags in boxes, weighed, labeled and palletized for storage. Packaged seed is placed into cold storage at 33 - 35 ° F or freezer storage at 2° F. Seed stored in these conditions can remain viable for many years.

### Seed cleaning

Our harvesting techniques produce seed that is "field cleaned". Seed purity values can range from 65 to 95% depending on the species and the harvest method. For restoration projects that use hydro-mulching, hand sowing or broadcast sowing this level of purity is not a problem. Sowing with a seed drill or other device that needs to have consistent seed flow, requires further cleaning at a facility like the Bend Seed Extractory in central Oregon. They have been cleaning most of our forb and grass seed. Through trial and error, they have perfected techniques for species that we've produced.

Forb seed production presents us with many challenges and opportunities. Since there are species being grown that represent many different families, huge variation exists in seed conditioning requirements, ability to plant the seed, plant culturing and seed harvesting. Most of the time the results are worth the efforts, especially when we can see more than a 100-fold increase in seed harvested from the original collection amount. Every growing and harvesting season we learn more and there is so much more to know. It is exciting to accept the challenges that each new forb species brings. On the horizon we believe there are opportunities in bulb production from forb seed and more container forb production. At J. Herbert Stone Nursery we are committed to the continued development of this program and we are pleased to share this knowledge with government agencies and the public.

# Opportunities to Improve Ectomycorrhizal Colonization within a Nursery Inoculation Program

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## Abstract

In order to propagate site-adapted containerized plants inoculated with the appropriate mycorrhizal fungi it is essential to understand mycorrhizal associations vary widely in structure and function. A nursery inoculation program should consider the following factors that will affect the success of ectomycorrhizae colonization: selection, timing and setting of inocula application, growing media characteristics, fertility levels, and the use of fungicides.

## Introduction

It is possible to state broad generalizations about the structure and function of the different mycorrhizal types that colonize the dominant vegetation in a gradient of climatic zones (Read 1984). Ericaceous plants, which dominate the acidic, high-organic heathland soils of the subarctic and subalpine regions are colonized by a group of ascomycetous fungi, giving rise to the ericoid type of mycorrhiza. This mycorrhizal type is characterized by extensive growth within (intracellular) the cortical cells, but little extension into the soil. Moving along the environmental gradient, coniferous trees replace ericaceous shrubs as the dominant vegetation. These trees are colonized by a wide range of mostly basidiomycetous fungi that grow between (intercellular) the root cortical cells forming the ectomycorrhizal type of fungi. Ectomycorrhizal fungi may produce large quantities of hyphae on the root and in the soil. At the warmer and drier end of the environmental gradient, grasslands often form the dominant vegetation. The fungi form arbuscles or highly branched structures within the root cortical cells, giving rise to the arbuscular type of mycorrhizae (Sylvia 1986).

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Ectomycorrhizae (ECM) are found on most tree species in temperate forests such as pines, spruces, firs, larch, birch, aspen, oak, and hickory. Mycorrhizal fungi usually proliferate both in the root and in the soil, and by this mechanism, mycorrhizae increase the effective absorptive surface area of the plant. In nutrient poor or moisture deficient soils, the increase of the absorptive area by the hyphae can lead to improved plant growth and reproduction. As a result, mycorrhizal plants are often more competitive and better able to tolerate environmental stresses than are nonmycorrhizal plants. Mycorrhizal fungi also interact with root pathogens. One major role of mycorrhizal fungi is the protection of the root system from endemic pathogens such as *Phytophtora* and *Pythium*. Lastly, ecological restoration often occurs on old mined land sites known to have high concentrations of heavy metals. Contingent upon the plant species and type of contaminant, mycorrhizae are able to filter some heavy metals to tolerable amounts for the plants (Norland 1993).

## Ectomycorrhizal Structures

Most plants with ECM have roots with a modified lateral root branching pattern. This pattern, heterorhizy, consists of short mycorrhizal lateral roots supported by a network of long roots. The long and short roots in heterorhizic root systems are fundamentally similar in structure, but short roots normally grow much more slowly than long roots (Kubikova 1967). Many ECM also have a sheath, or mantle, of fungal tissue that may completely cover the absorbing root. The mantle increases the surface area of the absorbing root and often affects fine-root morphology, resulting in root bifurcation and clustering. Pine roots with ECM are easily recognized by their bifurcated roots.

Mycorrhizal fungi also produce a hyphal network within the soil. This network consists of individual strands of hyphae and/or relatively undifferentiated bundles of hyphae called mycelial strands (Agerer 1991). The absorbing surface area of the root can be greatly increased by the presence of aggregated mycelia. Roussea *et al.* (1994) found that while the extramatrical mycelia accounted for less than 20% of the total nutrient absorbing surface mass in pine seedlings, they contributed nearly 80% of the absorbing surface. Some fungi also produce aggregated hyphal strands (rhizomorphs), which contain specialized conducting hyphae (sclerotia) which are resistant storage structures.

## Developmental Stages

Early colonization begins when the fungi adhers to the root epidermal cells near the apex of young actively growing feeder root. Attached hyphae have been observed 1-2 days after first contact with the root. After ECM associations have been established mycorrhizal short roots continue to grow by elongation and branching.

Later colonization is characterized by hyphae that have penetrated between the epidermal and cortical cells and formed a labyrinthine structure called the Hartig net that is able to form 2-4 days after root contact by the fungus. This extensive network is the site of nutrient and water exchange to the seedling by the fungi in return for photosynthates produced by the seedling.

The hyphal network that interconnects the structures produced by mycorrhizal fungi in the soil can also produce fungal fruit bodies used for reproduction. The reproductive structures of ECM fungi include epigeous fungi (mushrooms, puffballs, coral fungi, etc.) and hypogeal fungi, subterranean structures (truffles or truffle-like fungi).

## Factors Affecting Colonization

There are several factors that may affect whether or not inoculated seedlings are successfully colonized by ectomycorrhizal fungi. A primary consideration is the selection of inoculum. According to Marx and Kenny (1982) the most biologically sound inoculum is vegetative. Although spores can be collected and stored for years, they may take 3 to 4 weeks longer than vegetative inoculum to germinate and infect a root. However, Castellano and Molina (1989) reported the successful inoculation of six million container-grown Douglas-fir seedlings through the incorporation of a spore suspension of *R. vinicolor* into a fertilizer injector system and misting the spores onto the seedlings. At Bitterroot Restoration, Inc., many ectomycorrhizal species were successfully colonized by applying a commercial spore inoculum "Plant Success Soluble" by Mycorrhizal Applications as a soil drench. Prior to purchasing commercial inoculum, careful consideration should be given to the selection of the fungus species. Fungi for nursery applications should be early-stage with the physiological capacity to form abundant mycorrhizae on the desired hosts (Cordell and Marx 1994). Preference should be given to fungal species that fall into the multistage classification that occur in young and old forests alike in order to enhance the growth or stress tolerance of the host once outplanted. For example, several *Rhizopogon* species have been found from the nursery stage through forest rotation age in Chile (Garrido 1986).

Another consideration is the timing of the inocula application. Attention should be given to the seedling stage of growth upon inoculation. The seedling should have a fairly extensive feeder root system. Following inoculation ECM feeder roots grow much more slowly than the longer lateral roots Kubikova (1967) thus suppressing the growth of the seedling. The restricted growth of short roots may be necessary to allow ECM fungi time to form an association, since these fungi have difficulty colonizing more rapidly growing roots (Chilvers and Gust 1982).

The seedling should also have enough leaf surface area to produce enough photosynthates for continued growth and support of the fungus, which may assimilate as much as 20% of the carbohydrates produced by the host. Otherwise, suppressed growth of the seedling may result from the allocation of host photosynthates to the fungus. Gagnon and Langlois (1991) observed later colonization was more favorable to the growth of *rubra* L.

The setting in which the inoculation occurs can also affect the success of ectomycorrhizae colonization. The ability of mycorrhizal fungi to readily convert host-derived carbohydrates into forms specific for the fungi is influenced by many of the same factors affecting seedling metabolism such as temperature and photosynthetic active radiation (PAR). Ideally, inoculation should take place within a greenhouse where the temperate range is moderate. The inoculated seedlings should be under grow lights or moved out into direct sunlight. Intensities below 20% PAR have been shown to significantly reduced ectomycorrhizal development (Marx 1991).

The characteristics of the growing media such as texture can significantly affect the development of ectomycorrhizae on the host seedlings. Most ectomycorrhizal fungi favor good drainage and aeration (Cordell and Marx 1994). Growing media containing coarse-textured particles such as vermiculite promote ectomycorrhizal development.

The pH of the medium and irrigation water can also be important. Most fungi have pH requirements similar to their hosts, but some can tolerate unusual deviations such as *Rhizopogon*. Hung and Trappe (1983) found that an isolate of *Rhizopogon vinicolor* would grow well over a span of 4 pH units. On the other hand, research conducted by Marx and Kenney (1981) demonstrated a commercial formulation of mycelial inoculum of *Pisolithus tinctorius* had higher colonization rates in a much narrower pH range of 4.5 to 6.0. Preference should be given to fungal species having a greater tolerance to a broad pH range.

The effects of soluble N and P on ectomycorrhizae colonization may be an important factor depending upon the ectomycorrhizal species. spp. are able to form associations with many genera including; *Pinus, Picea, Abies, Pseudotsuga, etc.* (Smith and Read 1997). *Rhizopogon* spp. are little affected by high levels of soluble fertilizer. Inoculation with these fungi in commercial nurseries has been successful without altering the routine fertilization regime (Tyminska *et al.* 1986). In contrast, several researchers have documented increased levels of soluble N and P lowered ectomycorrhizal colonization of *Pisolithus tiuctorius (Crowly et* a1.1986, Rupp and Mudge 1985). Ideally, fertilization formulations can be manipulated for optimum seedling growth without detrimentally affecting mycorrhizal colonization.

Over the past 45 years many synthetic sulfur and other organic fungicides have been developed to replace the harsh, less selective inorganic materials. Thiazoles (etridiazol, ethaboxam, truban, terrazole, etc.) would be the fungicides of choice for nurseries growing ectomycorrhizal hosts (Landis *et al.1989).* The 5-membered ring of the thiazoles is cleaved rather quickly under soil conditions to form either the fungicidal isothiocyanate (-N=C=S) or a dithiocarbamate, depending on the structure of the parent molecule (Ware 1991). Dithiocarbamates (ferbam, polycarbamate, thiram, etc.) tend to inhibit mycorrhizal colonization, their use should be avoided. The dicarboximides (iprodione, captan, procymidone, etc.) are usually not inhibitory at low application rates; they can even be stimulatory. However, avoid drenching with these compounds, as they can be detrimental to ectomycorrhizae (Pawuk *et al.* 1980) .

There are non-destructive and destructive sampling methods for detecting mycorrhizae. A non-destructive method entails pulling the seedling plug out of its'container and determining the absence or presence of ECM through the visual detection of aggregates of hyphae. In many cases there may not be a proliferation of hyphae due to the optimal growing environment. A preferred method that destroys the integrity of the plug without causing any mechanical damage to the root system is to place the plug in a tray of water overnight to gently remove the majority of the growing media. When the detection rates of the two sampling methods were compared at Bitterroot Restoration, a 15% increase in the detection of mycorrhizae for *Pinus ponderosa* and a 40% increase for *Pinus edulis* were observed when using the destructive method of removing the growing media. Once the growing medium was removed, the bifurcation caused by the ectomycorrhizal colonization was easily identified using a hand lens.

## Conclusions

The establishment of an optimal growing environment for the seedling will greatly facilitate mycorrhizae colonization. The fungal symbiont should be able to tolerate a broad pH range and proliferate without adjusting the routine fertilization regime using soluble nitrogen and phosphorus. Familiarity with the different fungicidal compounds and their effects on ectomycorrhizae will mitigate accidental kills. Preference should be given to ECM that fall into the multistage classification. In most cases, the objective of a nursery inoculation program is not to achieve a physiological response of the host while in the nursery, but rather to establish symbiosis so that it can be effectively transferred to the field.

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# Propagation Successes, Failures and Lessons Learned

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## Abstract

Information on propagation of about 80 species of Pacific Northwest native plants is presented in table form, grouped by eleven protocols, followed by details about requirements for some specific plants, and rules of thumb for propagation techniques. Propagation of natives often involves trial and error, attempting multiple techniques and keeping good records. Communication with other propagators is invaluable.

Keywords

Native plants, seed germination, stratification, dormancy, cuttings, Pacific Northwest

## Introduction

I am fortunate to have access to a very good propagation facility. I do not work exclusively with native plants — they share an annual production schedule with more than 100,000 annuals and perennials for our gardeners and hundreds of ornamentals for nursery stock. Though not an expert, I am a professional, and it is my aim that my empirical, (i.e. trial and error) experience may save others time and effort. My work with about 80 native species is presented in tables, grouped under eleven protocols. I will discuss some discoveries I have made and rules of thumb which I find useful. To live up to the title of this presentation, I also list some failures. I use my more interesting failures and near misses to illustrate some of the lessons I've learned. My techniques are not the only ones, but they work for me, and the lesson of that is that by sharing experiences with others, we can make connections

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which will help us all solve our propagation problems in a variety of ways.

## Successes

I could also call this section "partial successes" because some were more successful than others, and some qualify as learning from mistakes, as you will see in the discussion of lessons and rules of thumb. Most seeds will germinate when natural conditions are simulated in an artificial environment. That may seem both obvious and easy, but it is not always the case. Some seeds will germinate under a wide variety of conditions, and others will stubbornly refuse to germinate even after careful handling, and therein lies the challenge. As technical as propagation can be, it is also an intuitive art. My self-taught technique has been to find out what I can about individual plants, then apply a few standard treatments. Toogood (1999) has wonderful, easily understood information on all types of propagation, and in a smaller space than any other reference I use. Young and Young (1986) contains information on steps to follow during collection, processing, storing and germination testing and trials for plants with unknown requirements.

When I research a plant I haven't propagated, I find that references often do not cover the one I am trying to grow, or that I need to alter recommended techniques in order to succeed (this is especially true for cuttings). Because I have actually applied the techniques described, I hope to contribute something new rather than repeating what we all know from our readings.

The adventure often begins with seed collection and storage. I also purchase seeds, and I have noted which seeds were purchased and which were collected in the tables which follow. The decision path I follow is fairly simple: if I cannot find germination information, I try germinating without treatment. This serves as warm stratification for those which need it, and if they do germinate, so much the better. If not, I begin to treat the seeds, first with cold stratification for at least 90 days, often longer. If germination is not good after a warm germination period (65-70° F.) I either try a second cold period, or I might start over with a new batch treated by scarifying or heat, depending on the ecology of the plant. If refrigerator stratification was used the first time, I would try them outside. If germination occurs anywhere along the way, I keep track of the percentage, and add or stop treatment depending on success of germination.

## Failures

These six species have shown a mystifying lack of germination despite best efforts and multiple treatments. I would call them complete failures, as opposed to those which yielded some information. I'm sure many people have nc trouble with these species, and I would love to hear from you!

- *Actea rubra* (have not tried second cold period)
- *Achlys triphylla* (digging and growing to divide work better)
- *Arctostaphylos ova-ursi.* Very few germinated after much treatment, (scarifying to within a few mm of embryo, warm stratification, water with vinegar, cold stratification and returning to warm). Reluctance to use sulfuric acid prevented me from using that method. Cuttings can be quite successful if taken in fall/winter.
- *Maianthemum dilatatum* (purchased seed has not germinated, have not collected). Division is successful.
- *Arctostaphylos columbiana* collected seeds were burned and given cold stratification outside, unburned seeds were given boiling water treatment and cold stratified to no avail. Fall and winter cuttings work moderately well, though not easy.
- *Trillium ovatum* (sown fresh, cold stratified).

## Lessons Learned

The real interest in propagation lies in gaining a feel for handling and working with plants so that the finished product turns out well. Though it is often difficult to describe in detail the knowledge gained through experience, I will attempt to discuss some guiding principles here.

**Protocol 1a.**

**Cold stratification: sow Nov to Jan. Place flat in cold frame. Alternatively, sow anytime and refrigerate in moist media at 38-41° F. Cold period required varies with species. Germination takes place the following spring or in the refrigerator. Flats outdoors should be shaded from sunlight. Watch for excessive warming or drying during sunbreaks and remove covers when necessary. Keep from freezing. Germination at 65-70° F. May germinate in refrigerator and should be removed immediately.**

| Genus | Species | Germination % | Purchased or Collected | Comments |
|---|---|---|---|---|
| *Acer* | *circinatum* | variable | C/P | Sow fresh, leave outside. Purchased seed did not germinate after repeated warm/cold cycles. Collected seed germinated moderately well. |
| *Amelanchier* | *alnifolia* | up to 75% | P | Germination better when flats are outdoors. Scarification does not seem to improve germination if stratified outside. |
| *Aster* | *chilensis* | 1-5% | P | Cold stratified in refrig and outdoors. Covered and uncovered. Not sure why seeds did not germinate well. A. subspicatus slightly better. Seeds from one of these potted plants appear to have germinated in the pot where they fell during the fall with ample water. Original seed may have dried out, or needed more light, or not have been viable. |
| *Aster* | *subspicatus* | 10% | P | see *A. chilensis* |
| *Cornus* | *unalaschkensis (canadensis)* | 100% | P | Cold stratified in refrig 5 months |
| *Cornus* | *sericea* | 90% | C | See *C. unalaschkensis* (could spend less time in cold). |
| *Fragaria* | *virginiana* | approx 80% | C | Put outdoors for cold stratification. Cover only very lightly or not at all. |
| *Fragaria* | *vesca* | approx 80% | C | If found growing with *F. virginiana* watch out for mixing of fruit and seed. |
| *Fritillaria* | *lanceolata* | | P | Germinated in cold frame with warm days (60° F. in frame) and cool to cold nights (low 30's to low 40's). Continued to germinate through spring and summer. Will die back quickly and suddenly, but look for small corms and replant in deep pots. Alternatively, use very deep flats to germinate and do not repot. |
| *Mahonia* | *aquifolium* | 14% | C | Low germination the first year, but seedlings may also be collected from underneath existing plants. Second winter of stratification may help. |
| *Mahonia* | *nervosa* | 30% | C/P | Place flats outdoors. Keep ungerminated flats, they may germinate in larger numbers during their second winter outdoors. May be a difference between purchased and collected. Can be stratified in refrigerator. |
| *Mahonia* | *repens* | >55% | P | Cold strat indoors 1 mo. Shift to warm for 2 mo. Back to cold 5-6 mo. |
| *Maianthemum* | *racemosa* | low to moderate (no counts) | C | Outdoor stratification more successful. Seedlings may die back during summer, but resprout strongly in the following growing season. Initial warm stratification before cold period may help. |
| *Malus* | *fusca* | >70% | P | Uniform germination after 4-1/2 mo in refrig. |
| *Oplopanax* | *horridus* | 10% | C | Outdoor stratification early Nov. First seedlings pricked out April. Still germinating in Sept. |
| *Philadelphus* | *lewisii* | approx 75% | C | Cold frame or refrigerator equally good. Germ within 90 days. Seedlings can sit in flat until ready to pot directly – better survival. |
| *Physocarpus* | *capitatus* | 50%+ | P | Cold frame or refrig strat. Easily grown from softwood cuttings. |
| *Ribes* | *bracteosum* | 19% | P | Stratified outdoors Dec. Germinated in May, continuing until July. May continue to germ with second cold period. |
| *Ribes* | *sanguineum* | | C | Cold frame or refrig strat. Easily grown from softwood cuttings. |
| *Rosa* | *sp.* | variable | C/P | All species need at least 10 to (preferably) 12 months of cold stratification. *R. pisocarpa* best germination rate. |
| *Rubus* | *parviflorus* | approx 85+% | C | Germination is better if flats left outside. Dec 15 sowing can be potted to 4" by first part of May. |
| *Spiraea* | *douglasii* | approx 75-80% | C | Germinates easily. Other spiraeas should be similar. |
| *Xerophyllum* | *tenax* | 25%+ | P | Cold stratify outdoors or in refrigerator. Seedlings are touchy and will die if they dry out. Keep quite moist, even wet, rather than letting them dry out. Slow growers. Use well-draining potting mix. |

### Protocol 1b.

**Fluctuating germination temperatures after cold stratification preferred (80 deg F Day/50 deg N)**

| Genus | Species | Germination % | Purchased or Collected | Comments |
|---|---|---|---|---|
| *Vaccinium* | *membranaceum* | approx 75% | C | Cold strat in refrig 3-4 months. *Vacciniums* prefer 50-50° nights and 80° days or approximation during germination period. |
| *Vaccinium* | *ovatum* | approx 75% | C | Collected seeds germinate after one cold period. Purchased seed may take second cold period. See also *Vaccinium membranaceum* |
| *Vaccinium* | *parvifolium* | approx 75% | C | Germinates well, follow same protocol as for other *Vacciniums*. Current year's seed used. |

### Protocol 2.

**Shorter cold period is necessary. It is easier to see when seeds begin to germinate if kept in the refrigerator (38° F.). Will germinate in refrigerator in large numbers.**

| Genus | Species | Germination % | Purchased or Collected | Comments |
|---|---|---|---|---|
| *Arbutus* | *menziesii* | 90% | C | Germinate in refrigerator in 90 days. |
| *Holodiscus* | *discolor* | >80% | C | Try to collect seeds from plants with insects – flower beetles may increase pollination. Very small seeds difficult to count for germ %, germ has been high for seed up to 2 years old. Will begin to germinate after 2 months in refrigerator. |

### Protocol 3.

**Pretreatment unnecessary. Small seeds often need light to germinate. Germination temp varies.**

| Genus | Species | Germination % | Purchased or Collected | Comments |
|---|---|---|---|---|
| *Allium* | *cernuum* | >89% | C | Germ temp 65-70° F |
| *Gaultheria* | *shallon* | 75% | C | Germinate at cooler indoor temp (58-65° F). Keep in flat longer than most seedlings, prick out in clumps. Slow growers. Delicate roots. |
| *Heuchera* | *micrantha* | approx >75% | P | Germinate in about 3-4 wks. |
| *Iris* | *tenax* | up to 90% | C | Keep at no more than 50° F. Old seed can be soaked in cold water, changed frequently for a week or so, or hung in toilet tank in mesh bags to pretreat with cold fresh water. All pacific coast irises similar. (Cole) |
| *Lupinus* | *polyphyllus* | 75%+ | C | Sow 55-65° F. Will start to germinate in 4-6 weeks, continue to germinate over next 2 or more months. Watch for stem rot. |
| *Penstemon* | *sp.* | approx 80% | C | Seed of *P. barrettiae* and probably most other Penstemons germinate in high numbers. Easy from cuttings. |
| *Rhododendron* | *macrophyllum* | high (seeds are tiny) | C | Seed several years old will germinate without treatment at 60-68° F. Best if they have light to germ. |
| *Tellima* | *grandiflora* | 90% | C | Germinate in 3-4 wks |
| *Tolmeia* | *menziesii* | 90% | C | Germinate in 3-4 wks |
| *Tiarella* | *trifoliata* | <50% | C/P | These probably need cold stratification. Lower germination than other saxifrages, sometimes none for many months. |

### Protocol 4.

**Pour boiling water over seeds, soak one day and follow with cold stratification period of at least 90 days. Germinate at 65-70° F.**

| Genus | Species | Germination % | Purchased or Collected | Comments |
|---|---|---|---|---|
| *Ceanothus* | most species | 38% | C | Cold strat in refrig Dec 15 to April 15 after boiling water soak. |

### Protocol 5.

**Some freezing during cold stratification is beneficial, fluctuating warm days/cool nights may also be the trigger for germination. Seedlings should not be disturbed until they go dormant naturally, then dug and the bulbs replanted in deep pots where they can remain for a couple of years.**

| Genus | Species | Germination % | Purchased or Collected | Comments |
|---|---|---|---|---|
| *Erythronium* | *oreganum* | 69% | P | Germinated with warm days/cool to cold nights in frame after 4 months. Died back early in plug tray, but bulbs had formed on many, pushing themselves out the bottom of plugs. Kruckeberg (1996) describes behavior of these seedlings and how to handle. |
| *Lilium* | *columbianum* | 10% | P/C | Difficult to keep seeds below surface, if on surface difficult to keep moist. Will germinate over a long period, and may die back after germination but still have live bulb. Toogood (1999) recommends keeping flats going for at least 2 years to allow leaves to emerge after dieback and bulbs to form. |

### Protocol 6.

**A period of warm moist stratification from 6 wks to 2 months before cold stratification of 3-4 months. Some may need scarification as well.**

| Genus | Species | Germination % | Purchased or Collected | Comments |
|---|---|---|---|---|
| *Dicentra* | *formosa* | variable | C/P | Seed may have to be sown fresh, undried. Warm stratification before cold stratification may help. Germination has not been consistently good. |
| *Rubus* | *spectabilis* | approx 80% | C | Warm stratify after scarifying, then cold stratify (outdoors works best) 4 months or more. |
| *Sambucus* | *racemosa* | 75 - 80% | C | At least 6 wks warm stratification followed by cold stratification in refrigerator or outdoors (best) for 90+ days. 15% may germinate during warm stratification. High N requirement while growing on. |
| *Sambucus* | *caerulea* | 15 - 50% | P | Lower germination than *S. racemosa*. Seedlings also have High N requirement. |

### Protocol 7.

**Simulated two year cycle of 3 months warm stratification-3 months cold stratification-3 months warm stratification-3 months cold before germinating at 65-75° F.**

| Genus | Species | Germination % | Purchased or Collected | Comments |
|---|---|---|---|---|
| *Symphoricarpos* | *albus* | approx 85% | C | Have always used freshly collected seed cleaned and dried. |

## Protocol 8. Ferns

**Follow standard protocols [e.g. Hardy Fern Foundation. (1998)] for ferns, keeping warm, humid and moist. Hand lens will help to observe proper moisture, germination and growth of prothalli (one month or longer), followed by fertilization and growth of sporophytes. Depending on species, a 1-gallon plant can be grown from spore in about 1 year. Use a moderately high N liquid feed through summer. Prick out in clumps for fuller plant.**

| Genus | Species | Germination % | Purchased or Collected | Comments |
|---|---|---|---|---|
| *Polystichum* | *munitum* | moderate | C | Grow quickly after sporophytes develop |
| *Polystichum* | *andersonii* | moderate | C | |
| *Adiantum* | *aleuticum* | high | C | Grow quickly |
| *Adiantum* | *aleuticum v. subpumilum* | | | Extremely slow growing. |
| *Dryopteris* | *expansa* | high | C | |
| *Blechnum* | *spicant* | moderate to high | C | |
| *Polypodium* | *glycyrrhiza* | moderate and very slow | C | Easiest propagation is by collecting dormant rhizomes from logs or trees, keep in a flat under mist until growth begins, then divide rhizome. Spores are few and bright yellow. Slow to germinate and slow growing. |

## Protocol 9. Trees

**Leave outside in flats or pots for the winter. Fresh seed should result in good germination in spring.**

| Genus | Species | Germination % | Purchased or Collected | Comments |
|---|---|---|---|---|
| *Thuja* | *plicata* | Moderate to high | C | |
| *Acer* | *macrophyllum* | variable | C | |
| *Acer* | *circinatum* | | C | If not fresh, may never germinate even with repeated treatment. |
| *Alnus* | *rubra* | Moderate to high | C | |
| *Corylus* | *cornuta var californica* | variable | C | Give the longest cold period possible. Nicking shells may help. Have not had any success with cuttings. |
| *Crataegus* | *douglasii* | 25 - 30% | P | No difference between cold stratification outdoors or refrigerator. Stratify 4-5 mo. |

## Protocol 10. Wetland plants

**Many will germinate without treatment at 60-65° F. Keep wet.**

| Genus | Species | Germination % | Purchased or Collected | Comments |
|---|---|---|---|---|
| *Scirpus* | *sp.* | Moderate (approx 50%) | C/P | |
| *Scirpus* | *tabernaemontanii (=S. validus ssp acutus)* | 30% | C | This species germinates better with cold stratification. Store wet in refrigerator. |
| *Carex* | *sp.* | Moderate | C/P | |
| *Juncus* | *sp.* | Moderate to High | C/P | |
| *Lysichiton* | *americanum* | 46-58% | C | DO NOT dry seed. Collect from inflorescence after it falls over and begins to disintegrate. Separate and sow fresh, store in refrigerator with natural jelly-like substance adhering. Have not tested storage life. |
| *Mimulus* | *guttatus* | High | C | Germinate readily, self sow; become weedy. |

### Protocol 11. Cuttings.

**Dilute water-based hormone (Rhizopon ®) to 500 ppm, dip stem ends 5-8 seconds. Dilute alcohol-based concentrate (Dip & Grow ®) 3:7 or 2.5:7.5 with water. Water based hormone may be watered on periodically. Medium used is Sunshine #4 ®. Sclerophyllous species should be covered with domes to keep humidity high, and leaves dry unless watering soil. Bottom heat of 68° F.**

| Genus | Species | Rooting % | Purchased or Collected | Comments |
|---|---|---|---|---|
| *Arctostaphylos* | *uva-ursi* | 50-75% (cuttings) | | Take cuttings in fall or early winter. At other will not root easily. |
| *Arctostaphylos* | *nevadensis* | | | same as *A. uva-ursi* |
| *Arctostaphylos* | *columbiana* | | | same as *A. uva-ursi* |
| *Ceanothus* | *sp.* | | C | Well expanded soft tip cuttings root well. Xeric species (*C. prostratus*) should not be misted. |
| *Cornus* | *sericea* | approx 80%+ | C | Must be collected before lenticels form on stem. See Toogood (1999) |
| *Garrya* | *elliptica* | 75%+ | C | Root well ripened soft tip cuttings with as little mist as possible, but never allow to dry out. |
| *Grindelia* | *integrifolia* | 100% | C | Root quickly from summer soft tip cuttings. Seeds have not been tried. |
| *Lonicera* | *sp.* | 90% | C | Cuttings of *L. hispidula, L. ciliosa, L. involucrata* root easily from soft tip cuttings and water-based liquid hormone at rate of 500 ppm. |
| *Mahonia* | *nervosa* | 56% | C | Cuttings can be taken in Fall or late Winter before new growth begins, using young plants and soft tip growth. Propagate by leaf bud cuttings. Water on hormone during rooting. |
| *Myrica* | *californica* | 85-90% | C | Greenwood cuttings in mid-late summer. |
| *Pachistima* | *myrsinites* | approx 75%+ | C | Have not tried from seed. Well expanded soft tip cuttings Mid-late summer root well. |
| *Penstemon* | *sp.* | 90%+ | C | Soft tip cuttings root easily. |
| *Philadelphus* | *Lewisii* | 75%+ | C | Do not use pithy, fast growing stems. Early summer, well-expanded soft tip cuttings. |
| *Physocarpus* | *capitatus* | 85-90% | C | Root easily from fully expanded soft tip cuttings. |
| *Potentilla* | *fruticosa* | 50-75% | C | Ornamental species root well from greenwood cuttings in mid summer. |
| *Ribes* | *sp.* | 75-90% | C | All *Ribes* species tried have rooted easily from soft tip cuttings. |
| *Salix* | *sp.* | 90% | C | All species will root at almost any time. Hardwood cuttings the easiest to handle. |
| *Sambucus* | *racemosa* | 50%+ | C | Green wood to semi-ripe cuttings with thicker stems root easily, could be put out as stakes? |
| *Sedum* | *sp.* | 99% | C | All root easily if laid on surface of soil and kept humid. |
| *Spiraea* | *sp.* | varies | C | Dormant hardwood cuttings have done better than summer soft tip. |

## Don't assume anything

Two examples will illustrate this important point. It appeared from rumor and my own reading that *Holodiscus discolor* was difficult to propagate. One reference suggested that seeds needed a very long period of cold stratification. I had not had any luck with cuttings, and decided to forge ahead and try seeds. After they had been in the refrigerator only two months, I discovered that they were germinating in huge numbers. This very useful plant and can be grown to gallon or two gallon size in one year including stratification time.

I also had a chance to experiment with *Lysichiton americanum* and make a midcourse correction. Seeds were collected, cleaned and dried as usual but when dried, they shriveled alarmingly. Another gardener and I had noticed a clear jelly attached to the ripe seeds, and I realized I should be seeing that it had a purpose. I collected a second batch and saved the sinkers separately from the floaters when cleaning them. The usual cleaning method is to discard the seeds which float in water and save the sinkers which have heavier and therefore viable embryos). In this case, the floaters may have had more of the jelly attached. I then sowed the dried seeds, 100 sinkers, and 1_00 floaters in separate flats. The dried seeds never did plump up, even after a lot of soaking. The floaters had a 60% germination rate, the sinkers a 50% rate initially, and over a few months all 200 of the non-dried seeds germinated. No doubt the jelly keeps the seeds moist until they germinate, even as water levels drop during the late spring and summer.

## Don't give up too soon

Some seeds either have a variable germination time or take an extremely long time to germinate, independently of the natural variation one would expect when working with wild collected seed. For example, I have had *Mahonia nervosa* germinate readily the first year, and a different batch of the same species fail to germinate until their second cold stratification period the next year. I have speculated that the slow germination might be because of age, lower moisture content in the dried seed, or other variables. The slow germinators were purchased, the faster ones I collected, however I have had the same thing happen with my collected seeds. Whatever the reason, for low germinators, a second winter of cold is often helpful. As can be seen from my examples of *Mahonia* flats, it is often worth it because you get enough plants to make it worthwhile, and you preserve some genetic variability by not throwing out the seeds too soon. The moss cover can obscure, but does not ruin your seedling crop. Try to get the liverworts out before they take over the flat.

## Stratification

Seeds must be moist for stratification. Tiny seeds will do better in the refrigerator where you can check often. They can be mixed with damp sand in a plastic carton or sow them in flats and put the flat in the refrigerator. Larger seeds can be folded into wet paper towels or peat moss and put in a plastic carton or plastic bags. If placed outdoors, it is a good idea to put plastic domes on the flats. Outdoor flats will need more water, they may need to be protected from freezing, although some freezing is recommended for some seeds, and they will need to be vented.

All stratification is not equal. For certain plants, there appears to be a difference in germination success between refrigeration and natural outdoor stratification. Alternating day/night temperatures may induce faster and better germination, or the length of time in cold, or possibly a light freeze. If I was able to compare the two methods, I have noted it in my tables.

## Pay careful attention

This may be obvious, but it is easy to forget to check your seeds often. Seeds will dry out in the refrigerator, and keeping moisture and temperature within limits is crucial. It is not easy to do this for seeds which are in a flat for months, and it's essential to check daily during periods of sunny weather. Once seeds imbibe moisture, it may take only one episode of drying to destroy the flat.

## Scarification

My favorite mechanical method is to put seeds in a rock tumbler with granite grit; even more abrasive products used in rock polishing could be used. *Rubus spectabilis* has very hard seeds and seems to benefit from the rock tumbler technique.

### Afterripening and/or warm stratification

I've noted the species which need some warm stratification before a cold period. This can also be used as a backup technique when seeds don't germinate well.

### Sowing media

Granite chicken grit, available in feed stores, is useful for covering seeds which tend to damp off. It also has the added effect of making the surface easier to water and prevents puddles. It will allow some light in if sown thinly, and grit can also be added to the soil mix to increase drainage in the medium without adding a lot of weight.

### Don't be afraid to fail

If there is a message in my presentation it is that failure equals learning. If you fail, try again and try something new. Don't avoid doing something because it might not work (see the part about not assuming anything). Intuition is extremely helpful in propagation, which is a lot like baking. You never know how it will turn out until you open the oven, and it sometimes involves minute adjustments during the preparation phase.

### A few species' idiosyncrasies

#### *Arbutus menziesii*

While it may be considered hard to transplant, Pacific Madrone is quite easy to grow in containers. Germination is high, and will occur in the refrigerator after three months. Seedlings are temperamental in needing very little water and no liquid fertilizer (leaves will burn). It is not recommended to transplant Madrone in the fall (Date. pers. comm) Spring is a better time for salvaging other Ericaceae, like Salal, and repotting Madrone.

#### *Sambucus* sp., *Rubus spectabilis*, *Dicentra Formosa*

Both *S. racemosa* and *S. caerulea* will germinate sporadically during warm stratification but the main germination comes after cold stratification. and prefer a period of warm stratification before cold.

#### *Rosa* sp.

These very hard seeds need an inordinately long cold period of nine to twelve months.

#### *Scirpus tabernaemontanii* (= *S. lacustris* ssp.

Following recommendations in Baskin and Baskin (1998) I will be storing my collected seed refrigerated in water. I have had only 10%-20% germination rates with seed stored dry and cold stratified.

#### Saxifrages in general

With the exception of *Tiarella trifoliata*, saxifrages appear to have similar germination requirements. They will germinate at about 65 degrees F. without any treatment in about a month. They may germinate better with light.

### "I Try All Things; I Achieve What I Can." (Herman Melville in Moby Dick)

Herman Melville explored whales and human nature. Plants may seem more humble, but the discovery process is no less thrilling and metaphysical. The important thing is to keep an open and adventurous mind. My goals have been to share some practical information I have discovered. Besides propagation experience with 80 or so species, I have tried to extract lessons from the time I've spent observing and working with seeds and plants. I invite others to contact me and establish a network of knowledge from which we can all benefit. By maintaining connections I believe we can increase our personal effectiveness, save time and improve our success rate.

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Coast Native Iris Society, Mercer Island, Washington provided germination information; Steve Erickson and Marianne Edain of Frosty Hollow Ecological Restoration, Whidbey Island, Washington; and John Brown of Judd Creek Nursery, Vashon Island, Washington dropped the occasional pearl of wisdom via e-mail listserves and personal communications.

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# Native Plant and Seed Production for High Elevation Restoration: Growing high elevation species in a northern plains desert

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## Abstract

Producing high elevation plants under arid, low elevation conditions presents several challenges including heavy textured soils, desiccating winds and open winters. Methods of reducing soil crusting and improving seedling emergence include using vermiculite or rice hulls during seeding, rolling, and light, frequent irrigation with sprinklers during germination and establishment. Snow fence creates additional winter cover to protect seed production fields. Seed harvesting of small-stature and/or indeterminate species is maximized by hand harvesting, *cyclic* stripping or vacuuming, or windrowing, all followed by after-ripening. Summer cuttings are a viable alternative for container production.

**Keywords**

Bareroot, container, vegetative, cuttings

## Introduction

The Plant Materials Center (PMC) at Bridger, Montana has been involved in high elevation restoration for over 25 years, working extensively with Glacier and Yellowstone National Parks. The work involves the restoration of linear disturbances created by highway reconstruction projects within both Parks. Although the total acres disturbed are relatively small, the length of the disturbance can be sig-

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nificant and may impact numerous sensitive habitats, including high elevation sites. Glacier and Yellowstone restoration policy mandates the use of native plants that are indigenous to each respective Park. Since most arable land is found in valley locations, the production of high elevation species often involves growing them under low elevation conditions. Despite the more favorable growing conditions characteristic of low elevation settings, problems arise when field growing alpine and sub-alpine species in a low elevation environment. This paper provides an overview of practical production considerations and techniques when attempting to grow high elevation plants. Small-scale production is emphasized, as well as the challenges that arise when growing high elevation species under low elevation conditions. Many of the techniques described reflect our local growing conditions, scale of production, equipment availability and staffing levels. Growers are encouraged to adjust their production methods to reflect their own situation, and to continuously experiment in order to improve propagation success.

## Production Location

The Bridger PMC is located in south-central Montana in the Clark's Fork Valley at an elevation of 3,700 feet (1,100 m) in a 10- to 12-inch (254- to 305-mm) annual precipitation zone. Most precipitation occurs in April through June (-5 in) and September through October (2.5 in) (USDAlNRCS 1998). The site is in close proximity to a broad range of habitat types for adaptation testing, from desertic valley bottoms to alpine sites over 12,000 feet (3,700 m). The location is classified as Major Land Resource Area 32 — Northern Intermountain Desertic Basin (USDA/SCS 1981) and falls in USDA Winter Hardiness Zone 4b (-20 to –25°F [-29 to —32°C]). Temperatures have ranged from 10°F (43°C) to –38°F (-39°C). The area is characterized by frequent and high seasonal winds with an average daily wind velocity of —9 mph (--14 km/h), and the highest average monthly wind velocities occurring in March and October (II to 12 mph [18 to 19 km/h]). The annual relative humidity averages —63 percent. Winters in Bridger are open with little consistent snow cover. The growing season is relatively long (—135 days) with a high number of solar days (USDAlNRCS 1998). The alluvial soils are fertile, deep, and have few rocks. There is a large and consistent supply of inexpensive, high quality irrigation water originating in the Beartooth Mountains. Low annual precipitation and relative humidity result in a low incidence of fungal disease-an important factor in seed production. Limitations include heavy textured soils, desiccating winds, drought, chinook conditions, temperature extremes, open winters, frequent summer thunderstorms, and rarely, hail.

A main production challenge at Bridger is soil texture. The soils in our valley are primarily alluvial deposits containing a high percentage of silt and clay. As a result, the surface of the soil crusts as it dries, impeding seedling emergence, especially of small-seeded grasses and forbs. Planting depth (usually <0.25 in [<0.6 cm]) is critical; and facilitating emergence, while avoiding seedling desiccation, is often difficult. There are several techniques that reduce crusting and improve seedling emergence. Add vermiculite, potting mix or rice hulls to the seed during sowing in order to facilitate seedling emergence. Light rolling of the soil surface prior to germination breaks the crust and aids emergence as well. Use frequent, light sprinkler irrigation, in lieu of flood irrigation, during early establishment to keep delicate seedlings moist and prevent soil crusting. There are factors to consider when using stationary or fixed sprinkler systems including timing of application, water quality, non-target irrigation and soil crusting from the impact of water droplets. Soil crusting is also exacerbated by heavy rain and irrigation. Avoid over-watering and surface pounding by large water droplets-two conditions that contribute to crusting. Use in-line valves to control the frequency and distribution of irrigation water. Sprinklers that distribute water over broad areas have large nozzle openings that produce large drops. Smaller nozzles can be used, but decreasing orifice size results in increased nozzle clogging and decreased coverage. Select a sprinkler head that produces a relatively fine droplet with the operating pressure of the system. It may be necessary to install filters to prevent clogging, and to decrease the spacing of sprinklers in order to obtain thorough coverage. For hand-line, this may mean using shorter sections of pipe or alternating long and short sections to increase overlap. Increasing water pressure will also reduce droplet size. A combination of excelsior blanket (American Excelsior Co., Arlington, TX) and sprinkler irrigation protects bareroot beds from wind desiccation and reduces crusting.

## Bareroot Production

There are several advantages to producing and using bareroot seedlings for restoration projects. The cost of production is low, the plants are well acclimated to field conditions, shipping is inexpensive, the size and weight of the seedlings lend themselves well to field planting, and the likelihood of weed contamination is low. On the other hand, bareroot plants require special handling and care that is unnecessary with containerized stock. Timing is critical in the lifting of bareroot plants because the stock must remain dormant until after field planting. In the northern Great Plains, chinook winds can create air temperatures in mid- to late winter that are conducive to premature bud break. If this warm period is followed by a rapid and large decrease in air temperature, plant mortality may occur in the nursery. Bareroot plants may break bud in the nursery in early spring before the soil is fully thawed. Avoid sowing bareroot beds in shaded areas that thaw slower than sunny areas. If necessary, remove mulches in late winter to early spring to allow complete thawing of the soil profile. It may be necessary to lift thawed stock, and to leave those plants frozen in the ground until a later date. At Bridger, all bareroot material is lifted by early to mid-March and then stored in a cooler until delivery. Untimely precipitation can cause lifting delays on slick clay soils. Deer and rabbit browsing of nursery stock in the winter can result in high plant damage, and growers should plan on installing tall (8-foot [2.4-m ]), multi-wire, electric fences.

Given an acceptable growing environment, bareroot production depends largely on water quality and quantity, as well as soil type. Since bareroot plants are grown in high densities, frequent irrigation is needed to reduce competition and produce a healthy seedling. In the arid northern plains, access to an inexpensive supply of high quality water will be a critical production factor. Ground water may contain high levels of salt that reduce germination and plant growth, and the cost of filtering and pumping may prove prohibitive. Heavy-textured soils cause seedling emergence problems with some small-seeded woody species, but are generally not significant unless the clay content is quite high. High densities of rocks can impair sowing and lifting operations, and will need to be removed.

Bareroot production works well at Bridger for serviceberry *(Amelanchier alnifolia),* kinnikinnick *(Arctostaphylos uva-ursi),* silverberry *(Elaeaguus commutata),* Oregongrape *(Mahonia repens),* common chokecherry *(Prunus virginiana),* Wood's rose *(Rosa woodsii),* thimbleberry *(Rubus parviflorus)* and common snowberry *(Symphoricarpos albus).* Site preparation, as it affects seed:soil contact and planting depth, has proven critical with our heavy-textured soils. Nursery beds are rototilled only when soil moisture is ideal. Excessive soil moisture during rototilling produces large clods, whereas dry soils become fluffed and require repeated rolling to firm. After rototilling the site is rolled with a lawn roller or culti-packer to firm the seedbed. Water is added to the roller until the rolled area is firm enough that foot prints leave less than a 0.25-inch (6 mm) depression. If a packer is used, a weighted board or pallet is pulled behind the packer or a tractor to eliminate ridges. We sow species needing just a cold, moist chilling in late fall, whereas we mid-summer sow plants requiring a warm, moist stratification prior to chilling. Our seeding rate depends on seed viability and purity, desired stock size, and anticipated germination percentage. We target production for 6 to 12 seedlings per linear foot (20 to 40 seedlings per meter) of row. Stocking densities greater than this tend to result in undersized, weak plants and an increase in damping-off diseases. Although our seeding rate varies, our rule of thumb is to sow approximately 25 to 50 viable seeds per linear foot (82 to 164 viable seeds per meter) of row. Our sowing depth is about two to three times the diameter of the seed. Three rows of fast growing species or four rows of slower growing species are sown on 12-inch (30-cm) centers within a 4-foot (1.2-m) bed. Five-foot (1.5-m ) alleys are left between beds to facilitate weed maintenance. Each bed is covered with 4-foot (1.2-m ) wide excelsior blanket to maintain soil moisture, reduce crusting, suppress weeds, and reduce seed loss to birds. Germination occurs the first or second spring after sowing. Two to three growing seasons are generally required, although Wood's rose is sometimes produced in one year. We use hand weeding and spot spraying to control weeds within the beds. At Bridger, the blankets are left in place and disintegrate before harvesting (usually 2 to 3 years). Harvesting is with a tractor-mounted "U" blade prior to bud break in the spring. It requires a 55-hp tractor to pull our 40-inch (102-cm) wide and 18-inch (46-cm) deep blade through our soils. Seedlings are stored at 34 to 37°F (1 to 3°C) and 75 to 90 percent relative humidity until shipping. Excessive moisture on our heavy textured soils has occasionally caused root rot diseases in serviceberry and seedling emergence problems with thimbleberry.

## Container Production

Container production from seeds works well for most high elevation species since growing conditions are easily manipulated in a greenhouse environment. We overcome seed dormancy with one of two production techniques. Entire lots of dormant seed may be treated prior to sowing, or dormant seed may be sown and then the containers warm stratified and/or cold chilled to break dormancy. The later technique is used when greenhouse, hoop house and cooler space is plentiful. At Bridger we use standard production techniques, growing most plants in 7- or 10-cubic-inch (115- to 164-cubic-cm) Cone-tainersTM (Steuwe and Sons, Inc., Corvallis, OR) in a commercial soilless mix for I to 2 years, depending on the species. Plants are started in the greenhouse in February through April and then moved in mid- to late summer to a ventilated hoophouse covered with 50 percent shade. The containers overwinter in the hoophouse until spring when they are either shipped or grown for another season. Grasses and (orbs are sometimes started directly in the hoophouse in mid-March or April and remain there until the following year. Supplemental heat is provided periodically in early spring and winter to prevent freezing. Species that have been difficult to container produce from seeds include dogtooth lily *(Erythronium grandiflorum),* Hitchcock's smooth woodrush *(Luzula glabrata* var. *hitchcockii)* (Wick 2001) and beargrass *(Xerophyllum tenax).* Saprophytic water molds have been identified as the likely cause of seed degradation of beargrass during cold, moist chilling (Grey 2001). Seed treatment with ThiramTM (Gustafson, Inc., Plano, TX) prior to chilling effectively controls this problem. Culture remains difficult, and trials are ongoing to identify the proper growing media, fungicide treatment and environment. The best results to date have been with the use of coarse vermiculite as a propagation medium.

Vegetative propagation may be preferred to sexual propagation when seed is limited, inaccessible, of low viability, has lengthy dormancy breaking periods, or there is a critical or short restoration interval. Good results have been achieved at Bridger with dormant cuttings of mountain alder *(Abuts incana),* redosier dogwood *(Corpus sericea),* plains cottonwood *(Populus deltoides* spp. *monilifera)* and willow *(Salix* sp.). Dormant hardwood cuttings of mountain alder taken in late October in Yellowstone Park rooted very well after a 48-hour soak in water immediately after removal from the donor plants (Scianna 1996). Good success at Yellowstone Park has been achieved with kinnikinnick, narrowleaf cottonwood *(Populus august folia),* black cottonwood *(P. trichocarpa),* russet buffaloberry *(Shepherdia canadensis)* and snowberry (Reid 2001).

Although dormant, hardwood cuttings are easy to handle and store, access to donor plants, winter browsing, seasonal staffing, and reduced winter greenhouse operations may limit their use. Good success has been achieved with several species using summer cuttings. Correct donor plant selection and proper harvesting, transport and storage of these perishable cuttings is critical (Scianna et al. 1998). Vegetative propagation with summer cuttings has worked well at Glacier Park for arctic willow *(Salix arctica),* undergreen willow *(S. commutata),* Drummond's willow *(S. drummondiana),* rock willow *(S. vestita),* as well as broadpetal strawberry *(Fragaria virginiana)* from runners (\Vick 2001). Summer cutting propagation has proved successful at Yellowstone Park with redosier dogwood and snowberry (Reid 2001). Species successfully propagated at Bridger from summer cuttings (>50 percent rooting) include kinnikkinnick, common juniper *(Juniperus communis),* creeping juniper *(Juniperus horiontalis),* Western Labradortea *(Ledum glandulosum),* twinberry honeysuckle *(Lonicera involucrata),* Oregongrape, common chokecherry, Wood's rose, American red raspberry *(Rubus idaeus),* thimbleberry, mountain snowberry *(Symphoricarpos oreophilus)* and common snowberry (USDA/NRCS 1997). An often over-looked option with herbaceous plants is to use summer cuttings for asexual propagation. Although propagation of wildflowers by seeds is generally preferred, there are circumstances when seed production is impractical such as seed scarcity, low viability, long dormancy periods, unknown propagation protocols, or the need for rapid restoration of critical or high visibility sites. Vegetative propagation success has been achieved in small trials with yarrow *(Achillea millefolium),* smooth aster *(Aster laevis),* Pacific aster *(Aster chilensis),* fireweed *(Epilobium augustifolium),* and fuzzytongue penstemon *(Penstemon eriautherus).*

## Seed Production

The low cost of production and ease of storage, shipping, transport and planting often favors using seed for high elevation restoration. In most cases the limited quantity and quality of wildland seed warrants production under cultivated conditions. At Bridger, we follow the same standards and production techniques with high elevation species that we use for low elevation plants (Smith and Smith 1997, Holzworth et al. 1990). A firm, granulated, weed-free seedbed is prepared as described in Bareroot Production. We sow 30 to 50 viable seed per linear feet (98 to 164 seed per meter) of row using a two-row drill, and space the rows 36 inches (0.9 m) apart. Our row spacing reflects the design and size of our tractors, cultivators and gated pipe, as well as access for hand weeding and harvesting. Seedling emergence through crusted soils is aided by rolling or sprinkler irrigation as previously described. Heavy sprinkler irrigation during anthesis is avoided at Bridger, although few adverse effects have been noted from untimely rains. This may be due, in part, to apomictic seed production or the presence of included anthers. Flood irrigation can be used after stand establishment to prevent pollen loss during irrigation. When multiple species are to be grown in close proximity, seed increase fields should be designed and zoned so that each species can be isolated during irrigation.

It may be necessary to container produce and then transplant species with poor seedling emergence. This technique is also useful when resource protection is critical, there is a short restoration schedule, or seed is limited. We start 7- to 10-cubic-inch (115 – to 164-cubic-cm) Cone-TM in the greenhouse in mid- to late winter and then line them out in the field by hand or with a mechanical transplanter (Mechanical Transplanter Co., Holland, MI) in early summer. This technique is more economically viable if the species is long-lived and likely to produce seed for several years. We have used this technique successfully with smooth aster, slenderbeak sedge *(Carex athrostachya),* Dewey sedge (C. *deweyana),* chamisso sedge (C. *pachystachya)* (Husby and Lesica 2001), tufted hairgrass *(Deschampsia cespitosa),* fuzzytongue penstemon, silverleaf phacelia *(Phacelia hastata)* and alpine bluegrass.

As equally important as timely irrigation is proper weed control. Weeds reduce seed production and contaminate pristine high elevation habitats upon reintroduction. Weed maintenance practices vary with field size, production species, weed species, equipment availability and staffing levels. Small-scale seed production (<0.25 A [<0.1 ha]) is maintained by a combination of hand-rouging and spot spraying. Weed barrier can be used in small seed production fields of high value, prostrate forbs to control weeds and capture shattered seed. In larger production fields we use bromoxynil during the year of establishment to control broadleaf weeds without damaging grass seedlings.

Several 2,4-D products will remove broad-leaved weeds from mature grass fields (2 years or older); however, the control of grassy weeds in grass fields remains difficult. In studies conducted at Bridger, fall-applied metribuzin at 0.36 lb/A (0.4 kg/ha) and oxyfluorfen plus metribuzin at 0.98 plus 0.27 lb/A (1. I plus 0.3 kg/ha) controlled 98 and 95 percent of downy brome Bromus tectorum in perennial grass seed production fields (Whitson et al. 1997). This research led to a 24 C (EPA Special Local Needs Label) permit for use of these products in grass seed production in Montana and Wyoming. If seed germination is delayed and weed competition is high, we use 2 to 4 percent glyphosate to control weeds. It should be noted that relatively few herbicides are specifically labeled for use in grass seed production fields.

Although insect predation has historically been low at Bridger, a new pest emerged in seed production fields in 2001. Timothy billbug *(Sphenophorus zeae)* (Lanier 2001) infestations of alpine bluegrass and alpine timothy *(Phleum alpinum)* seed production fields caused premature ripening of seed heads in both species. Although the infestation did not appear to impact seed production, this species can cause serious seed losses in perennial grass production fields. Premature browning of seed heads in April is the first indication of a problem. Control of this insect is during the active adult stage, and applications of insecticides after infestation will not improve the current season's production.

Alpine plants grown at low elevation tend to mature early in the summer, and seed production and maturation appears more responsive to heat-units than day length. Although harvest occurs in late May or June in Bridger, stands are irrigated and maintained over the remaining growing season to assure seed production the following year. Depending on the weather, culture and species, stands may produce seed crops for one to three years before dying out. Seed harvesting of many high elevation species is labor intensive because of their low stature, indeterminate ripening and tendency to shatter. Many small stature species are hand harvested and allowed to dry and after-ripen on a tarp prior to processing. Indeterminate species can be harvested in several fashions. An estimate of maximum ripe seed can be made and the entire crop direct combined or hand harvested at one time. Another option is to windrow the fields and allow after-ripening for several days prior to combining. A similar technique is to hand-harvest the seed heads or collect them on a tarp fixed to the bottom of a swather, and then allow them to after-ripen on a tarp in a protected location. Cyclic stripping of seed heads by hand or machine is labor intensive, but has proven effective for indeterminate species. We have used a Flail-Vac' (Ag-Renewal, Inc., Weatherford, OK) seed stripper successfully on larger fields of blue wildrye *(Elymus glaucus),* although some shatter occurs at each operation. Smooth aster is also highly indeterminate and we have used swathing, hand clipping and vacuuming to harvest seed. Modification of a tractor-drawn leaf vacuum has proven successful for harvesting fluffy seeded species including Aster (Kujawski et al. 2001), and should prove successful with smooth aster as well.

Local weather patterns also play an important role in the seed production of high elevation species. As an example, limited winter snow cover at Bridger often results in winter desiccation of field grown alpines. We use 4-foot (1.2-m) high snow fence to capture enough snow cover to provide protection against extremes of temperature and desiccating winter winds. The fence is located at 20- to 30-foot (6- to 9-m) intervals and oriented perpendicular to alpine seed production fields in order to increase snow cover. Leaves are also used to mulch exposed areas between rows. High elevation species that lend themselves well to seed production appear in Table I.

One underutilized group of plants for high elevation restoration are the sedges *(Carex* sp.). Seed production of sedges began in 1998 at Bridger as a result of monitoring data from Glacier Park indicating good establishment, survival and persistence of several sedge species on roadside restoration projects. Numerous sedges grow at high altitude and some require less moisture for successful establishment than popularly believed. Sedges are easy to grow in containers, establish well in the nursery and produce abundant, viable seed - depending on

**Table 1. High elevation species for seed production.**

| | |
|---|---|
| common yarrow | *Achillea millefolium* |
| smooth aster | *Aster laevis* |
| other aster | *Aster* spp. |
| golden sedge | *Carex aurea*[1] |
| slenderbeak sedge | *Carex athrostachya* |
| Dewey sedge | *Carex deweyana* |
| Hayden's sedge | *Carex haydeniana*[1] |
| smallwing sedge | *Carex microptera*[1] |
| black alpine sedge | *Carex nigricans*[1] |
| chamisso sedge | *Carex pachystachya* |
| Payson's sedge | *Carex paysonis*[1] |
| Ross' sedge | *Carex rossii*[1] |
| tufted hairgrass | *Deschampsia cespitosa* |
| blue wildrye | *Elymus glaucus* |
| slender wheatgrass | *Elymus trachycaulus* |
| alpine willowherb | *Epilobium anagallidifolium*[1] |
| fireweed | *Epilobium angustifolium*[1] |
| northern sweetvetch | *Hedysarum boreale* |
| fuzzytongue penstemon | *Penstemon eriantherus* |
| silverleaf phacelia | *Phacelia hastata* |
| alpine timothy | *Phleum alpinum* |
| alpine bluegrass | *Poa alpina* |
| slender bluegrass | *Poa gracillima*[1] |
| arrowleaf groundsel | *Senecio triangularis*[1] |
| other groundsels | *Senecio* spp.[1] |
| creeping sibbaldia | *Sibbaldia procumbens*[1] |
| alpine hairgrass | *Vahlodea atropurpurea* |

[1] – Species not produced at Bridger, but production success likely.

the species. Direct seeding of seed production fields may be possible, but has not yet been attempted at Bridger. The plants are long-lived and continue to expand in size each year with what appears to be a commensurate increase in seed production. The PMC has achieved good success with sedges, especially slenderbeak sedge that produced over 350 lb/A (393 kglha) of bulk seed in 2001. Other high elevation sedges worth testing include golden sedge (Carex *aurea),* Hayden's sedge (C. *haydeniana),* smallwing sedge (C. *microptera),* black alpine sedge (C. *nigricans),* Payson's sedge (C. *paysonis),* dunhead sedge (C. *phaeocephala)* and Ross'sedge (C. *rossii).*

## Summary

Small niche markets growing native plants for restoration and other end uses are emerging for beginning, as well as established growers. The lessons we have [earned growing native, high elevation species lend themselves well to other restoration and horticultural applications. Producing high elevation species in a low elevation environment poses unique challenges that can be overcome with proper planning and production methodologies. Land managers should anticipate and budget for the increased expense of producing local ecotypes for restoration work.

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# Growing and Managing Site Specific Plants in the Nursery

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## Abstract

Cornflower Farms has its own in-house propagation and record keeping techniques for managing multiple site-identified species that are grown for either contract or open markets concurrently. These techniques help ensure that quality plant materials will be produced in the right quantity and on-time. This paper describes these techniques which are twenty years in the making and still evolving.

**Keywords**

contract growing, site identified plant material, record keeping, stratification, native plant propagation

## Introduction

Cornflower Farms began as a small propagation nursery with an emphasis on natives. Managing projects 20 years ago was simple. A couple of three-ring binders of notes, a lot of tribal knowledge and only a few small projects made it relatively easy to keep things straight. As the nursery grew, so did the number and size of projects and people involved. As we grew a protocol and information system evolved to help manage our quickly accumulating knowledge. This presentation will describe our current propagation and management tools.

Our overall goal is to produce a healthy well-adapted plant that is ready for the rigors of the wild. To accomplish this goal, a variety of tools are employed including collecting site-specific plant materials and using special containers, soil mixes, microbial inoculants and other aids.

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The contractual aspect of our operation demands, for every project, that we meet or exceed the number of container-grown plant materials required and that they be delivered on time. Coordinating propagation and production for as many as 50 species for a single project takes skill and precise record keeping and planning by our production team. Our nursery can have as many as fifty sizable growing contracts per year. We also produce sizable numbers of site-identified open stock from plant communities from all over Central and Northern California. Coordination of collections, materials, and labor is demanding and requires a fair amount of fine-tuning.

The diversity of project locations and associated plant communities is great. It can include those from salt marshes in San Francisco Bay, riparian projects in the Central Valley, mitigation for endangered plants in the Sierra foothill, high elevation projects in the Tahoe Basin and the East and West slopes of entire Sierra Nevada Range extending to the southern Cascades. This requires that we provide a large variety of suitable growing climates by micromanaging our nursery growing areas to best meet the unique and specific needs of all these associated plant materials.

Every year we do our plant projections to fill both our project and open stock needs for over 800 different plants. These projections help us produce a collection calendar for the entire year. This calendar is a great aid for tracking and coordinating the large number of sites that we collect from each year. It, in turn, creates the production calendar that establishes stratification, sowing, cutting, and production potting schedules.

## Methods

### Setting projections

Projection numbers are prepared in the summer/fall of the year before plant materials are needed in order that seed and cutting collection amounts can be determined. Order forms are mailed in August to our regular customers and are returned within 30 days. Sales totals from the previous year are evaluated to determine the quantity of open stock we want to produce by specie. Anticipating potential near-term needs for a given region is a skill in itself . It requires familiarity with potential collection locations and assimilating information acquired through phone contacts, requests for bids and awareness of development activities in the region. This information, although helpful in determining how much of a given plant specie might be needed from each collection region, can still result in over/under production and is inherently risky. All this information is tabulated and entered into our database with the previous year's records showing projections and actual plant numbers produced.

We have developed a simple but large plant information database that documents both our successes and failures in propagation. Information on rooting percentages, propagation timing and other critical factors, cultural needs, fertilization requirements, preferred soil mix, container preferences among other factors is recorded. At present we keep this information in a simple spreadsheet format and specific information is transferred to worksheets for use by production staff as needed. This data combined with our current inventory and order data gives us a fairly accurate snapshot view of plant production requirements for the coming year (Figure 1).

In the year 2000, we implemented a new accounting computer program; Flexware; that was customized to track our specialized inventory as well as provide inventory history. We are currently developing a complementary production module that will allow us to efficiently store all plant data and more efficiently transfer specific production information to work sheets as-needed and to help coordinate production calendars and eliminate duplication of paper trails.

### Production calendar

Once we have our goals set, we can start our production calendar. In June our collection calendar is prepared. A breakdown of collection locations for both projects and open stock arc made. Collection permits at various locations are procured.

Amounts of plant materials to be collected per specie are estimated for each region. Approximate time of collection

| Location | Lot # | | Item Number | Warehouse | Quantity | Strat Unit | Strat Ready | Source Id | Description | Job/ Project | Customer | Sales Order |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | MUHRIG | Muhlenbergia rigens | | | | | deer grass | | | |
| | | | MUHRIG | *NT/FS-6g per flat | | | | | | | | 5 |
| | | | MUHRIG | **2002 PROJ: DIV: HP/LN:8000 LT6: LT8: TB: DP: TP4: G:1000 fall F: FIF: | | | | | | | | |
| | | | MUHRIG | **2002 POT: DIV: RP/LN: LT6: LT8: TB: DP: TP4: G: F: FIF: | | | | | | | | |
| | | | MUHRIG | ***2001 PROJ: DIV: RP/LN: 10000 LT6: LT8: TB: 3000 DP: TP4: G: 1000 F: FIF: | | | | | | | | |
| | | | MUHRIG | ***2001 POT: DIV: RP/LN: 8428 LT6: LT8: TB: 2940 DP: TP4: G: 264 F: FIF: | | | | | | | | |
| | | | MUHRIG | ***** | | | | | CF LANDSCAPENORTH | | 2/7/90 | |
| 08-GG | 00-00204 | 01 | MUHRIG-01 | 90 | 124 | | | HEDGEROW0 | HEDGEROW FARMS/LINCOLN PLACER CO | STOCK | | 0 |
| 11-RR | 98-00014 | 01 | MUHRIG-01 | 90 | 21 | | | UNKNOWN- | UNKNOWN SOURCE | STOCK | | 0 |
| | | 01 | MUHRIG-01 | | 0 | 25 | 0 | 1/1/2002 | 9/1/2002 | | BALMOU1 | 14116 |
| | | 01 | MUHRIG-01 | | 0 | 50 | 0 | 11/15/2001 | 11/15/2001 | | CITDAV1 | 14058 |
| | | 01 | MUHRIG-01 | | 0 | 5 | 0 | 11/14/2001 | 11/14/2001 | | JUDWAE1 | 14056 |
| 01-EE | 00-00204 | LN | MUHRIG-LN | 90 | 26 | | | HEDGEROW0 | HEDGEROW FARMS/LINCOLN PLACER CO | STOCK | | 0 |
| 01-EE | 99-00014 | LN | MUHRIG-LN | 90 | 50 | | | PLA0HA0D- | PLA/LINC/L/NHEDGEROW FARMS | STOCK | | 0 |
| 01-II | 99-STOCK | LN | MUHRIG-LN | 90 | 26 | | | UNKNOWN- | UNKNOWN SOURCE | STOCK | | 0 |
| AA-15 | 98-00014 | LN | MUHRIG-LN | 90 | 1011 | | | UNKNOWN- | UNKNOWN SOURCE | STOCK | | 0 |
| BB-12 | 98-00014 | LN | MUHRIG-LN | 90 | 540 | | | PLA0HA0D- | PLA/LINC/L/NHEDGEROW FARMS | STOCK | | 0 |
| BB-15 | 00-00165 | LN | MUHRIG-LN | 90 | 1804 | | | PACCOSTSEE | PACIFIC COAST SEED/BUTTE CO | STOCK | | 0 |
| BB-16 | 00-00165 | LN | MUHRIG-LN | 90 | 3087 | | | PACCOSTSEE | PACIFIC COAST SEED/BUTTE CO | STOCK | | 0 |
| DA-11 | 00-00204 | LN | MUHRIG-LN | 90 | 11 | | | HEDGEROW0 | HEDGEROW FARMS/LINCOLN PLACER CO | STOCK | | 0 |
| | | LN | MUHRIG-LN | | 0 | 300 | 0 | 1/1/2002 | 9/1/2002 | | SOONUR1 | 13649 |
| | | LN | MUHRIG-LN | | 0 | 200 | 0 | 11/21/2001 | 11/26/2001 | | TRILAN1 | 14111 |
| AA-03 | 00-00165 | SF | MUHRIG-SF | 90 | 1 | | | PACCOSTSEE | PACIFIC COAST SEED/BUTTE CO | STOCK | | 0 |
| AA-03 | 00-00204 | SF | MUHRIG-SF | 90 | 2 | | | HEDGEROW0 | HEDGEROW FARMS/LINCOLN PLACER CO | STOCK | | 0 |
| AA-06 | 00-00204 | SF | MUHRIG-SF | 90 | 3 | | | HEDGEROW0 | HEDGEROW FARMS/LINCOLN PLACER CO | STOCK | | 0 |
| 15-HH | 00-00165 | SS | MUHRIG-SS | 75 | 16.0 | 018 | | PACCOSTSEE | PACIFIC COAST SEED/BUTTE CO | STOCK | | 0 |
| 15-HH | 00-00204 | SS | MUHRIG-SS | 75 | 13.8 | 018 | | HEDGEROW0 | HEDGEROW FARMS/LINCOLN PLACER CO | STOCK | | 0 |
| CC-01 | 98-00014 | TB | MUHRIG-TB | 90 | 1440 | | | PLA0HA0D- | PLA/LINC/L/NHEDGEROW FARMS | STOCK | | 0 |
| CC-06 | 00-00204 | TB | MUHRIG-TB | 90 | 1470 | | | HEDGEROW0 | HEDGEROW FARMS/LINCOLN PLACER CO | STOCK | | 0 |
| | | TB | MUHRIG-TB | | 0 | 44 | 0 | 11/7/2001 | 12/30/2001 | | DAVGIL1 | 14008 |

*Figure 1. Projecrions and Inventory*

is noted in our records are adjusted accordingly depending on weather conditions prevailing during the current year. We do 75% of our own collections. For the remaining 25% we use experienced collectors who have special knowledge of a specific area like the Sierras or Tahoe Basin. All new collectors are first met with in the field to best ensure we obtain the seed quality and diversity that we desire. In the fall it is hard to be at all the locations at the same time to collect ripe seeds before animals or weather conditions remove or damage the crop. All of this information is put into a spreadsheet that can be sorted by seed, collection, collector and date to be collected. This now can be put in a calendar format for collection and seed orders can be sent to our outside collectors so they can plan for our numbers.

## Collection

We consider a variety of factors when determining the suitability of plant materials found in the field for collection We do a field slice test to determine the quality and ripeness of the seed from a tree or bush. Overall health of the collection plant is evaluated. For example, for *Heteomeles arbutifolia;* toyon; we look for specimens which are free of apple scab and leaf spot. "Trueness" of a plant specie is often determined by its location and surroundings. Was it a "planted native" with an unknown source or a natural accruing one? Is there non native species located that can cross with it and compromise the seed crop seed? This is particularly true with *Platanus racemosa;* western sycamore; and *Platanus occidentalis;* American sycamore. Furthermore we do multiple plant collections of a specie in an area to ensure genetic diversity.

## Logging In and seed cleaning

Propagation has become a business of managing many numbers. Every plant that comes into the nursery is tracked numerically during its entire life at the nursery. All materials are assigned a Lot number (indicating year and numeric order of collection), location (which changes as the plant moves through the various stages of propagation at the nursery), Source ID code (giving the coordinates of the collection site), Customer ID code and Jobl Project ID code. An example can be seen in Figure 2.

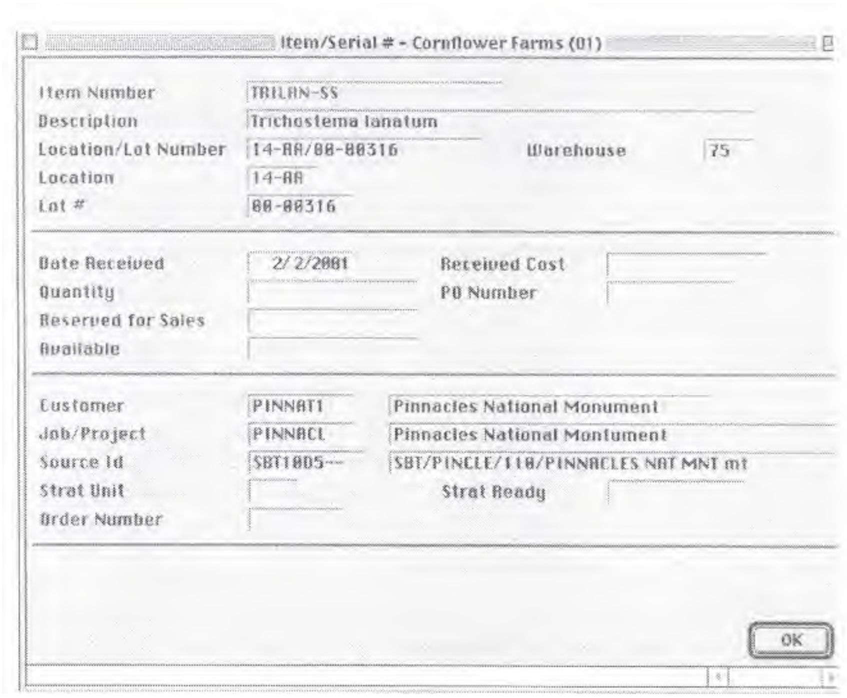


*Figure 2. Data Entry Screen*

In the case illustrated by Figure 2, the seed is located in area 14, the walk-in cooler bin A. The lot number 00 means the material was collected in 2000 and -00316 means it was the 316$^{th}$ entry for the year. Warehouse 75 means it has been cleaned; the customer is Pinnacles National Monument. The project is located at the Pinnacles; and our collection location is San Benito County with the given map coordinates.

When new seed comes into the nursery, a Seed Data Sheet is completed using our own firsthand information or from an outside collector. Seed Data Sheet information includes collection location, altitude, area temperature range, orientation of plant and site conditions, and seed zone of the site. A Lot Number is assigned to the each collection of a species that follows it through its life at the nursery and beyond. We have had clients call several years later after obtaining one of our propagules needing to find out the original source of the plant. Our records can be retrieved if the client must follow landscape specifications for site identified material at sometime in the future. A Source ID is given to track the exact map coordinates of the collected species. The seed is then entered into the computer with all of its data as new inventory. As the seed is cleaned, stratified, sown or transplanted this information will follow along on all labels, in the database and all of the way to the final invoice.

## Pre-treatment, stratification and sowing calendar

After all of our seeds have been collected, cleaned and in storage we make up the Statification and Sowing Calendar. All of the stored seed inventory is exported from the computer into a spreadsheet and combined with our plant information database and sorted to determine timing for a seed going into stratification and flat sowing. Generally we want seeds ready for sowing into flats or containers starting March 1st. The computer sorting groups the seeds into 4 start dates:

November = 3 month stratification and warm/cold combined stratification

December = 2 month stratification

January = I month stratification

February/ March = seed sown directly into flats that do not need to be stratified

Seeds will be coming out of stratification from February through March to be either direct sown into containers or into seed flats for future transplanting.

Pretreatments, such as acid treatments to breakdown a seed coat, are completed before a seed is stratified. Seed is prepared for stratification by soaking it in water for 24 hours then mixing it with a slightly moist course perlite or peat moss depending on the seed. It is them put into a zip lock bag with a breather straw or, as for larger seeds, put into a 13 gallon capacity white plastic bag with I" tube tied into the top so the seeds can breath. Every two weeks the inventory of seeds in the cooler is exported to a spreadsheet and a cooler status is performed. Each seed bag is gone through, the moisture level is adjusted, disease problems noted and, if necessary, treated and inspected for the emergence of radicals. These reports are used to start preparing worksheets for sowing and to update the projects progress report. If a problem is detected early we will often have enough time to redo seed pretreatments so that order-specified plant numbers can still be met. The seed planning process is always changing as new orders are placed and seed failures occur.

### Labeling

Extensive labeling of plants is critical in order to successfully keep various lot numbers and different projects with the same species from getting mixed. Our labels will have all of the information that is tracked with the seed or cutting on it. Projects are given colored label combination that, at a glance, any employee can readily make the distinction what is part of one order and what is not. When over 50 site identified projects are ongoing, we can have color codes combining up to three color labels.


*Figure 3. Label*

## Specialized Growing Practices

We have developed specialized growing techniques to best deal with the wide diversity of materials we propagate. This includes optimum timing for cutting production in the greenhouse, fine tuning seed pretreatment and propagation timing, as well as creating the right environment for the plant to grow on.

The wide range of plant communities that we propagate selected species requires that we often perform micro-management techniques and provide microclimates for sensitive crops. Our summer temperatures often reach 100-108° F. Black containers can produce extremely high soil temperatures and imprecise watering can cause root diseases. Inappropriate placement of a given specie in the nursery can also result in root or foliar disease problems. Overhead watering on some species can cause leaf spot, scab, powdery mildew, or worse, downey mildew. We strive to use preventative measures and adhere to strict sanitation practices. Training of employees and assigning one person to the task of spot watering of sensitive crops is also important. For many species we grow it is important to know the minimum amount of water a plant can grow with. Employees must also need to detect when a potential problem is developing such as leaf color changes or new growth shows stress or distortion.

Bilingual signage and training on sanitation and plant specific watering methods is very important for many of these materials to be successfully produced. We have created areas that are watered from below with capillary mats for plants that are susceptible to foliar disease problems in summer from overhead irrigation. We group plants that need to be on the dry side, need good drainage, and reprieve from the 100 degree plus days. Many of our growing areas are equipped with a manually retractable shade cloth (generally 55% - 63% that can be drawn at transplanting then opened after a short but potentially lethal transplant shock period has past. It can also be used for those short intervals when temperatures soar over 105, especially for crops prone to root disease. Managing a project means daily hands-on attention and fine-tuning by the grower.

The selection of containers used in restoration growing can be critical. The end goal for all of us is to produce an excellent root system void of circling roots. Over the years Cornflower Farms has promoted unconventional containers other than 1 and 5 gallons that were the norm for projects 10 - 20 years ago. Working with the contracting agents over the years, the containers we originally promoted have now become the norm on most bid specifications. Over the years we have worked with the container producers to add features to these containers to increase air pruning and directing roots downward to further reduce problems with circling or pig tailing roots in the drain holes. Intermediate steps in propagation for materials destined for shifting to larger size containers are important. Transplants with circling roots may not be detected in a final root ball but can be the demise of a plant 10 years after outplanting.

## Contract Growing

How are contract grown site identified projects handled within the mainstream of production? On the onset of a new project a contract is drawn defining the specifics of the job. This helps keep a clearer picture in-mind for us and the client on the terms that were agreed upon up-front to apply throughout the term of the contract. We require a 50% deposit to start a contract. This covers the early stages of material purchasing and labor to initiate the project. Each project has a binder set up that records all of the plant progress reports at their various stages and communications with the client. Each plant is given a Plant Sheet where every step for that species is documented from number of cuttings, rooting percentages, transplanting timing, etc. A collection strategy is created for the project and broken down into how many collections, for what species and at what time. Materials are produced in excess from between 30-50% over final numbers through every stage of propagation. Final sorting of a project will release only the most vigorous and finished plants. Production timing is worked derived by looking 'backwards'; starting from the estimated shipping date to insure that the plants will be of size and not overgrown.

Delays are common on restoration projects so the probability of this happening as the project progresses is always considered when transplanting into the final container. We communicate often with the client on timing. Production timing is also determined by where the project is going. High elevation projects need 18 months to collect, stratify and finish a plant before the snows fall. Lower elevation projects we need less time; 12-14 months, and are usually synchronized for planting with the first significant rain (October to December).

Some bids are released too late due to contract release delays to grow and deliver when desired. We have developed special relationships with some repeat clients to allow us to anticipate projects coming down the pipeline. We try to advise them, for instance, what seeds that will need to be collected prior to initiation of the contract in order to fulfill their orders.

## Conclusion

Producing plants that will flourish in the rigors of the wild is the ultimate goal for any restoration grower. New research and methods *need* to be reported on regularly as they are developed. Meetings such as this symposium are often the best way to keep on top of developments in growing techniques. Although we are becoming evermore-proficient managers of numbers, we will be in awe of the subtleties of plant propagation forever!

# Considerations in the Propagation of Rare Plants

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The propagation and reintroduction of rare plants is sometimes necessary to preserve a species. This is often because the native habitat of the species is threatened by development, invasive species, or other types of habitat degradation.

The reintroduction of rare plants can be seen as a very special type of restoration activity. However, reintroductions have a special difference. The goal of a restoration is generally to restore the function of an ecological community. The function of a reintroduction is to maintain the genetic potential of a species. This means that, at every step of the process, special care must be taken to protect the genetic diversity found within natural populations. Given all the steps necessary, this can be an exceedingly difficult task.

The first step is to collect seed. Because you are not collecting all seed from all plants in all populations, you must take a sample. By virtue of the nature of sampling, you are only taking a small representation of the total genetic diversity found in the population. How many seeds (or cuttings) you take, from how many plants, depends somewhat on the size and spatial arrangement of the populations as well as, potentially, information about the breeding system of a species. Those species which outcross may have a higher genetic diversity in the population.

The next step is to germinate the seeds. Almost no species have 100% germination, and rare plants may have been through a genetic bottleneck that further reduces seed viability. Therefore, even though you may have collected 10,000 seeds, if only 50% germinate, you will lose potentially 50% of the genetic potential of your sample. Similarly, even if you get good germination, you may further lose species through propagation losses during the seedling stage.

*Proceedings of the Conference: Native Plant Propagation and Restoration Strategies. Haase, D.L. and R. Rose, editors. Nursery Technology Cooperative and Western Forestry and Conservation Association. December t 2-13, 2007 . Eugene, OR.*

As the plants are held in the nursery, readying them for planting out into the wild, a number of losses may occur. First, there may be losses due to disease or predation by animals or insects. Anticipating these may be an important step to protecting the evolutionary potential of the species. Be sure to have regular and careful examinations of the species, along with such things as yellow sticky traps to monitor for many types of insects, bait or traps for slugs, and protection from grazers such as rabbits.

In the nursery there may also be "artificial selection" that contributes to a loss of genetic information and may make the plants less fit for the wild. Artificial selection occurs in nursery or greenhouse conditions, where the plants that survive best are those that are suited to the pampered regimen. Plants that like regular water and food  and there are plenty that have not evolved that way!) may be more likely to do well. When these "hothouse flowers" are installed in a dry, low nitrogen prairie, for example, they may find themselves less fit to survive than their sisters that did not survive the nursery regimen.

Finally, there are no guarantees that anything transplanted, whether a rhododendron in your garden or a rare plant in a wetland, will survive transplanting. Special care should be given to ensure that each plant is given the best chance. In the maritime Pacific Northwest, fall is a great time to plant - there will be plenty of precipitation and the roots will continue to grow during the winter, allowing the plant to be established by spring. Planting techniques that may help ensure survival of each plant include making a planting hole that is big enough around without being too deep, backfilling the hole with soil from the site, not special rich imported soil, and watering, weeding, and aftercare for some time, until the plant establish. Basic horticultural texts can provide information about planting techniques.

It is inevitable that some genetic potential will be lost in any reintroduction program - that is why on site conservation is *always* the preferred method. However, by carefully and consciously working to sample widely and provide the best horticultural care possible, the losses may still be minimal enough to allow the reintroduction to be a useful conservation tool. Any such reintroduction should be done in conjunction with the approval of such agencies as the United State Fish and Wildlife Service and the approval of the owners of the land from which seed collected and outplanting will be conducted.

# The Target Seedling Concept: The First Step in Growing or Ordering Native Plants

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## Abstract

The target seedling concept was developed for reforestation but can and should be applied to the propagation and use of native plant materials. The basic idea is that seedling quality is determined by outplanting performance (survival and growth) rather that characteristics or standards measured at the nursery. This means that there is no all-purpose plant, but that each project will require different types of plant materials including seeds, nursery stock, unrooted cuttings, and bulbs or rhizomes. The target plant materials concept is not static but must be continually updated and improved with feedback from outplanting projects.

### Key words

restoration

## Introduction

The first native plant nurseries in North America were forest tree nurseries which were established in the early 1900s. Back then, the entire process was very simple: nurseries produced the seedlings which were then shipped for outplanting. Foresters took what they got and there wasn't much choice. In those days, tree planting was a mechanical process of getting the seedlings in the ground in the quickest and least expensive manner. Not much thought was given to seedling quality, different stock types, or the possibility of matching seedlings to outplanting site conditions.

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In the last 25 years, however, more science has been infused into the process. New research into seedling physiology and better-educated customers have revolutionized traditional concepts of reforestation. We now understand much more about how tree seedlings function--both in the nursery and after outplanting. In particular, the advent of the container seedling showed the importance of nursery cultural practices and vividly demonstrated important concepts like hardiness and dormancy. Today's seedling customers are very well educated, they know what they want, and they have many choices.

## The Target Seedling Concept

The target seedling is a relatively new concept but the basic idea can be traced back to the late 1970s and early 1980s when new insights into seedling physiology were radically changing nursery management. A literature search of my Forest Nursery Notes database found nothing published on "target seedlings" before 1990. In that year, however, the Western Forest Nursery Association conducted a symposium to discuss all aspects of the target seedling, and the resultant proceedings are still a major source of information on the subject (Rose et al. 1990).

One basic tenet of the target seedling concept is that seedling quality is determined by outplanting performance or how the seedlings will be used-"fitness for purpose" (Ritchie 1984). Although it may sound rather intuitive and obvious, this represents a major change in the way nursery stock is grown. For example, most people consider a Douglas-fir *(Pseudotsuga menesii)* seedling as a generic product that only varies in stock type and price. Forest nurseries distinguish between ecotypes (e.g. variety *glauca)* and ornamental nurseries offer different cultivars (e.g. "Carneflix Weeping"). Until the target seedling concept was introduced, however, nurseries did not grow seedlings for specific outplanting sites. Now, we realize that seedling quality cannot be merely *described* at the nursery, it can only be *proveu* on the outplanting site. The target seedling concept emphasizes that there is no such thing as an "all-purpose" tree seedling. A nice looking seedling at the nursery will not survive and grow well on all sites.

Although originally developed for reforestation, the target seedling concept should also be applied to native plant propagation and outplanting. Therefore, my objective is show how these concepts can be used to define the best type of plant material for any outplanting project.

## Defining Target Plant Materials

The process consists of six sequential, but interrelated steps (Figure 1):

### 1. Project objectives

It is critically important to define the reasons why plant materials are needed before the project is even started. In traditional reforestation, commercially valuable tree species that have been genetically-improved for fast growth are outplanted with the ultimate objective of producing saw logs or pulp. The target plant materials for a restoration project will be radically different, however, as commercial products are not a consideration. For example, the objectives of a watershed restoration project might consist of stopping erosion, stabilizing the stream bank, and ultimately

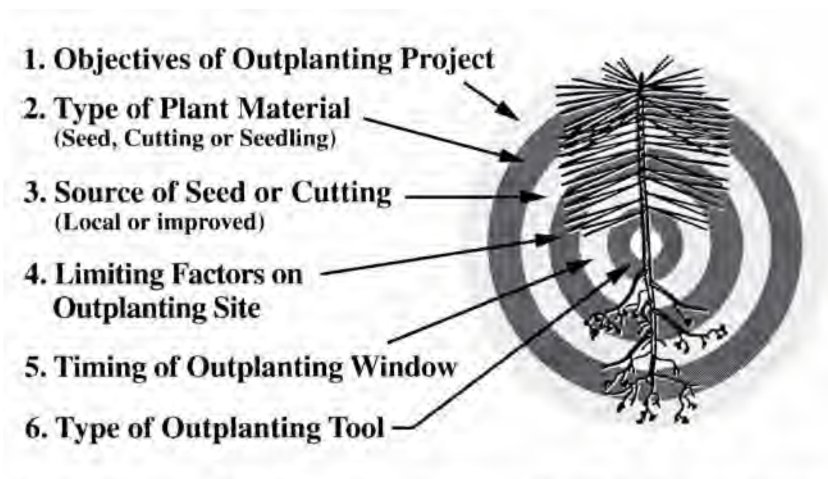


*Figure 1 - The process of defining the target plant materials for a specific outplanting site consists of six steps.*

restore a functioning plant community (Figure 2). This is an interesting example because the target plant materials for riparian restoration would include hardwood cuttings for bioengineering structures such as brush mattresses, wattles, and vertical bundles as well as nursery stock (Hoag and Landis 2001).

Fire restoration projects will have different objectives depending on the plant community and the ultimate use of the land. The project objectives for a burned rangeland might be to stop soil erosion, replace exotic weed species with natives, and establish browse plants for deer or elk. Target plant materials for this project might include a direct seeding of native grass and forbs, followed by an outplanting of woody shrub nursery stock. For a burned commercial forest, however, the plant materials would be grass seed to stop erosion and then outplanting of tree seedlings to bring the land back to full productivity as soon as possible.

Another project might be to restore plants that are in danger of going extinct in a particular habitat. For example, Short's goldenrod *(Solidago shortii)* is an endangered plant that can only be found in 14 populations in a small geographic area in Kentucky (Baskin et al. 2000). Fortunately, this plant is relatively easy to propagate from seed and grows well in greenhouses, so the target plant material would be container seedlings.

Restoration objectives need to be clearly defined; however, the terminology can be rather intimidating with technical terms such as enhancement, rehabilitation, reclamation, and revegetation. See Newton (1993) for a comprehensive discussion of these terms and how they relate to restoration project objectives.

## 2. Types of plant material

Native plant restoration projects use a variety of different plant materials and establishment techniques: transplanting wildlings, direct sowing of seeds, outplanting nonrooted cuttings or rhizomes, and propagating and outplanting of nursery seedlings or rooted cuttings. Transplanting wildlings consists of digging up and moving existing plants from adjacent sites and outplanting them in the project area. Besides being expensive due to the labor involved, this technique has little merit in ecological restoration unless the operation is carried out for the purpose of salvaging unique or rare plants from an area destined to be destroyed (Landis et al. 1993).

Plant materials are introduced into most restoration projects by direct seedling, planting of nonrooted hardwood cuttings, or outplanting bareroot or container nursery stock (Table I).

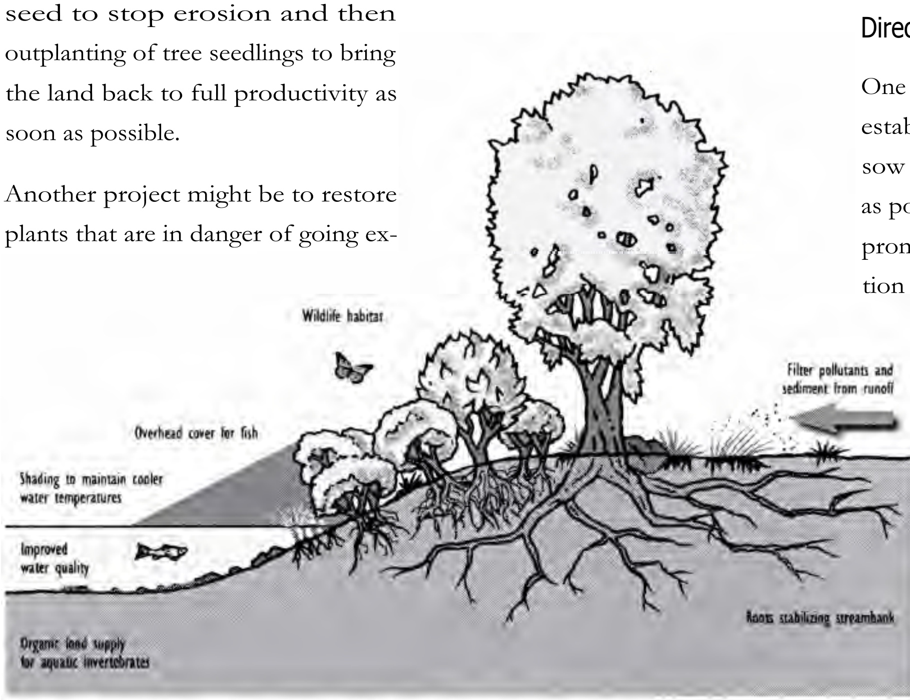


*Figure 2 - Restoration project objectives are the first step in defining target plant materials.*

### Direct seeding

One of the most obvious methods for establishing plant communities is to sow seeds of as many native species as possible, and then hope for rain to promote rapid and uniform germination and establishment. Seeds can be broadcast sown by hand or machine drilled. The effectiveness of direct seeding varies with the species of plants, the harshness of the site, and the objectives and time frame of the planting project. The principal advantages of direct seeding are that it is inexpensive, relatively easy, and allows seedlings to develop a natural

**Table 1 - Consequences of Using Different Types of Plant Materials in Restoration Projects**

| Consequence | Seeds | Nonrooted Cuttings | Nursery Stock |
|---|---|---|---|
| Efficient Use of Plant Material | No | No | Yes |
| Cost of Establishment | Low | Moderate | High |
| Ability to Establish Harsh Sites | No | No | Yes |
| Option of Using Specific Genotypes | Yes | Yes | Yes |
| Precise Scheduling of Establishment | No | No | Yes |
| Control of Species Diversity | No | Some | Yes |
| Control of Plant Spacing | No | Some | Yes |

Modified from Landis et al. (1993)

root system. However, there are many drawbacks (Table 1). Native plant seeds from the proper seed source are often difficult to obtain or are very expensive, some species do not produce adequate seed crops each year, and the seeds of others, such as the white oaks *(Quercus* spp.), do not store well. Seeds of many diverse species require special cleaning and processing before they can be sown. Even if the proper seeds can be obtained and properly distributed over the site, predation from birds and rodents, competition from weed species, and unpredictable weather often reduce establishment success. And finally, with direct seeding, it is difficult to control species composition and plant spacing over the project area (Landis et al. 1993).

Direct seeding is generally recommended for grasses and forbs, although certain woody shrubs and trees can also be established under some conditions. In California, direct seeding of native oaks has been quite successful and the Department of Fish & Game has direct-seeded alkali bullrush *(Scirpus robustus)* for restoration of wetland wildlife habitat in the Delta. Reduction of weed competition and protection from seed predation were certainly key factors in the success of these projects (Landis et al. 1993).

## Planting nonrooted cuttings

Many riparian and wetland species can be successfully propagated on site by collecting cuttings and planting them without roots. The term "stem cutting" generally referring to traditional hardwood cuttings but also includes rhizomes and tubers, which are modified underground stems. Specialized roots, such as bulbs and corms, can also be used to propagate some plants. Under ideal conditions, planting nonrooted cuttings can be a very cost effective means for establishing certain vegetation types. There are several limitations, however (Table I). Because this is a type of vegetative propagation, care must be taken to sample from a variety of individual plants and populations so that adequate genetic and sexual diversity will be represented. Since vegetatively propagated plants retain the sexuality of the parent, care must be taken to collect from both male and female plants to insure future seed production.

Nonrooted hardwood cuttings are prepared from long whips collected from shrubs or trees on the project site or from stock plants at a nursery. If a large number of cuttings will be needed for several years, it might be wise to establish stooling beds at a local nursery. Whips should be collected during the dormant season when the potential new root formation is highest. They are cut in sections which range from 12 to 24 inches (30 to 61 cm) in length and 3/8 to 3/4 inch (10 to 19 mm) in caliper. When planted properly in moist soil and under favorable conditions, cuttings will form new roots which follow the receding water table down as the young plant develops during the first growing season.

An interesting type of hardwood cutting sometimes used in riparian restoration projects is called the stump or pole cutting (Hoag and Landis 2001). These poles are often six feet (1.8 m) in length and 8 to 12 inches (20 to 30 cm) in diameter and are obtained by cutting the major branches or stems of existing cottonwood or willow trees. The key to success with these extremely large nonrooted cuttings is to plant them deep enough so that the butt end reaches the water table (Figure 3). The soil must also be coarse enough to allow enough air exchange at these depths to support adequate root growth. Unfortunately, this is not always the case. If the bottom of the pole cutting loses contact with the ground water or if soil conditions are not favorable for root production, shoots called "watersprouts" will form

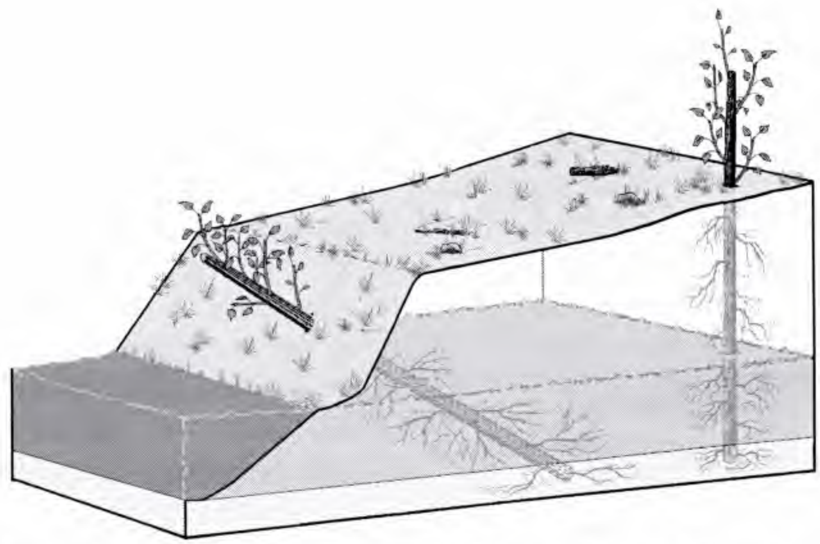

*Figure 3 - Willows, cottonwoods and other riparian trees and shrubs can be establishing by pole plantings that are long enough to always reach ground water (from Hoag and Landis 2001)*

but quickly wither. Another drawback to the use of pole cuttings is the obvious impact to the "donor" or stock plants from which the cuttings were obtained. However, this is not a problem when collecting poles from special stooling beds in nurseries.

Rhizomes, tubers, bulbs and some types of root sections are used for the vegetative propagation of certain grasses and wetland plants. Grass and sedge rhizomes and root sections have been successfully used for wildland outplantings, such as a prairie restoration project at Jepson Prairie in California (Landis et al. 1993). Because of difficulties with seed dormancy, the Mason State Nursery in Illinois produces rooted cuttings and root divisions of several species of prairie forbs, woodland understory and wetland plants (Pequinot 1993). The advantages and drawbacks for rhizomes and root sections are the same as those for nonrooted hardwood cuttings (Table 1).

## Nursery stock

For projects where rapid and complete establishment of the desired plants is critical, outplanting seedlings or rooted cuttings that were raised at a nursery is usually the best method. Nursery stock is the most efficient establishment method when seeds or cuttings are in a short supply or are expensive (Table 1). When done properly, the high rates of success make nursery stock one of the most appropriate methods for natural resource planting projects. Nursery production can be coordinated with the project timetable, so that the target species will be available at the proper size and in the outplanting window. When forced to meet human time scales, natural reproduction is extremely slow so utilizing nursery stock increase the success rate (Table I). Some plants produce seeds infrequently and others only at irregular intervals. Nurseries have the ability to collect seeds during those infrequent seed production years and store them until needed. Propagating plants in nurseries can significantly improve seed use *efficiency* because, in nature, many seeds are eaten by predators and young germinants are lost to drought and other stresses. Plants that propagate vegetatively cannot disperse to new areas very quickly and so planting nursery stock can accelerate this process. Natural plant succession relies on chance whereas planting can assure that the desired species will quickly establish in the desired location and at the proper spacing (Landis et al. 1993).

The most serious disadvantages of using nursery stock include the high initial cost and the lag time between ordering the seedlings and outplanting them (Table 1). However, when computing costs, restoration project managers should consider using the cost per established plant rather than the nursery price. The shorter establishment time with seedlings compared to seed or other plant materials can also make nursery stock more attractive. Nursery culture can take from as little as 6 months to as long as 4 years depending on seed availability and the desired stocktype (Figure 4). Obviously, good planning and communication between the customer and the nursery is an important consideration.

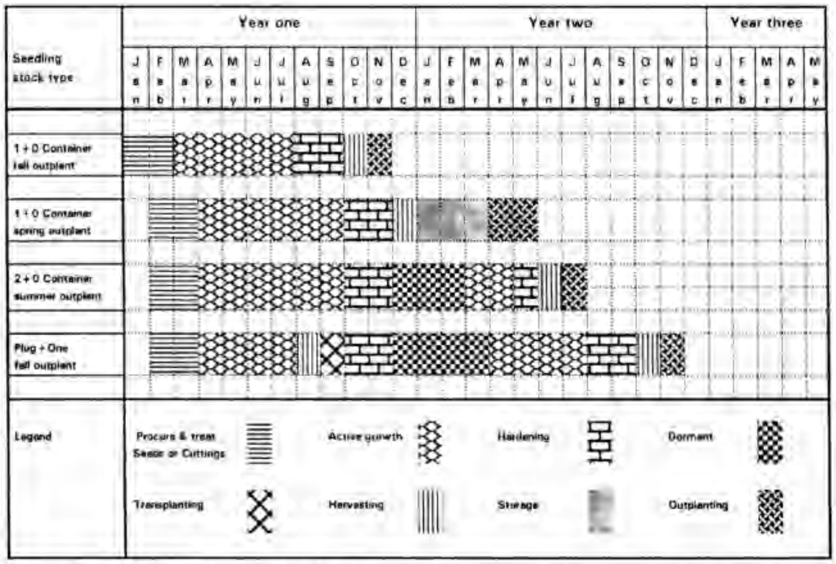


*Figure 4 - These crop production schedules illustrate the time required to produce several nursery stock types (from Landis et al. 1999).*

### Proper source of Seed or vegetative plant material

If nursery stock is the desired target plant material for a restoration project, then the question of genetics must be considered. There are two separate but equally important components: local adaptation and genetic diversity.

#### Local adaptation

Many native plants can be propagated by seeds but they must be collected on or near the project area. "Seed source" is an idea familiar to all forest nursery managers and reforestation specialists. They know that, because they are adapted to local site conditions, seeds should always be collected within the local "seed zone." Forest and conservation nurseries grow plants by seed zone, which is a three-dimensional geographic area that is relatively similar in climate and soil type. Each zone is stratified by elevation bands that are typically 500 feet (150 m). Seed source affects seedling performance in a couple of ways: growth rate and cold tolerance. In general, seedlings grown from seeds collected from higher latitudes or elevations will grow slower but tend to be more cold hardy during the winter than those grown from seeds from lower elevations or more southern latitudes (Landis et al. 1995). Seed zone research has not been done on many other native plants or for vegetative plant material, but it is only intuitive that the same concepts should apply. Therefore, it would be prudent to always collect seeds or cuttings from the same geographic zone and elevation in which the seedlings are to be outplanted.

#### Genetic diversity

The second genetic consideration when planning for target plant material is to try and capture all the genetic and sexual diversity that exists on the project site. So, when harvesting either seeds or cuttings, collections should be made from as many individual plants as possible to maximize genetic diversity and, in the case of cuttings, to ensure that both male and female plants are equally represented. Guinon (1993) provides an excellent discussion of all factors involved in preserving biodiversity when collecting seeds or cuttings, and suggests a general guideline of 50 to 100 donor plants.

Using a local source for seeds or cuttings and collecting from enough individuals to maintain genetic and sexual diversity should be basic tenets of restoration ecology.

### 4. Limiting site conditions

The classic ecological "principle of limiting factors" can also be applied to the target plant materials concept. This principle states that, when a process is governed by several factors, its rate is limited by the factor that is closest to the minimum requirement. In the case of a restoration project, target plant material specifications should be developed by identifying which environmental factors will be most limiting to survival and growth on that particular site. For example, on a fire restoration site in New Mexico, shallow soils and grass competition are the most serious factors. On the Kenai peninsula in Alaska, however, cold soil temperatures are limiting to plant survival and growth.

Temperature measurements in the shallow rooting zone do not exceed 50 (10 ˚C) during the summer and research has shown that root growth almost stops completely below this temperature threshold (Landis 1999). By identifying potential limiting factors on the outplanting site, the plant materials that will have the best chance of establishing can be selected.

One potentially limiting outplanting site condition deserves special mention: mycorrhizal fungi. Reforestation sites typically have an adequate complement of mycorrhizal fungi that quickly infect outplanted seedlings whereas many restoration sites do not. For example, severe forest fires or mining operations eliminate all beneficial soil microorganisms including mycorrhizal fungi. Therefore, seedlings destined for these sites should receive inoculation with the appropriate fungal symbiont before outplanting.

Nursery managers must work with seedling customers to identify which environmental factors will be most limiting on each outplanting site. Through these discussions, specification for the best target plant material can be formulated to maximize survival and growth under these specific site conditions.

### 5. Outplanting window

The timing of the restoration project must also be considered when defining target plant materials. The outplanting window is the period of time in which environmental conditions on the outplanting site are most favorable for survival and growth of seedlings or cuttings. As you can see, this component is closely related to the previous one on limiting site conditions. However, the outplanting window also must consider other operational constraints such as access to the site and availability of labor.

The best outplanting window is usually defined by limiting factors and soil moisture and temperature are the usual constraints. In the Pacific Northwest, seedlings are outplanted during the rains of winter or early spring but, in the Southwestern states, the summer monsoon season offers another potential window. In Alaska and other northern latitudes, the outplanting window is later in the summer when soil temperatures are at their peak. In recent years, there has been a renewed interest in fall outplanting. This is primarily due to the availability of properly conditioned container stock. Whereas outplanting projects used to be scheduled when the first fall rains began, foresters are finding that soil temperature may be just as important as soil moisture in determining the outplanting window.

Using information from the seedling customer, nursery managers can develop a crop propagation schedule that will produce the target plant material at the proper time for outplanting. These schedules are unique in that they are constructed in reverse order. Starting at the desired date of delivery, the nursery manager plans backwards to determine how much time will be required to produce seedlings or other plant material with the target specifications (Landis et al. 1999). Crop production schedules for different container seedling stock types are illustrated in Figure 4.

### 6. Outplanting tools

There is an ideal planting tool for each outplanting site. All too often, foresters or restoration specialists develop a preference for a particular implement because it has worked well in the past. However, no one tool will work under all site conditions. For example, special planting hoes called hoedads are popular in the steep terrain on the Pacific Northwest but the level terrain in the Southern Coastal Plain allows machine planting, which is much more efficient. Often, planting contractors will choose the implement that gets plants or cuttings into the ground as quickly as possible. This obsession with productivity is understandable but can be counterproductive. For example, the dibble was developed as an easy and quick way to outplant container seedlings. Experience has shown that dibbles work reasonably well on sandy soils but that they create a compacted soil layer in clay soils which inhibits root egress.

New outplanting tools are continually being developed. Specially modified hoedads called "plug hoes" are now available for container stock. The "Expandable Stinger" is a mechanized probe that is used to outplant hardwood cuttings or special "long tube" seedlings in riparian restoration areas (Figure 5). One of the most attractive features of the Expandable Stinger is that the hydraulically powered head can plant seedlings or cuttings into existing rock rip-rap or in dense vegetation such as berry thickets (Steinfeld and Landis 2001). The Waterjet Stinger has recently been developed to outplant nonrooted hardwood cuttings (Hoag et al. 2001). For planning purposes, nursery managers must know which planting tools will be used in advance so that they can develop proper plant material specifications such as seedling root length and volume or cutting length and diameter.

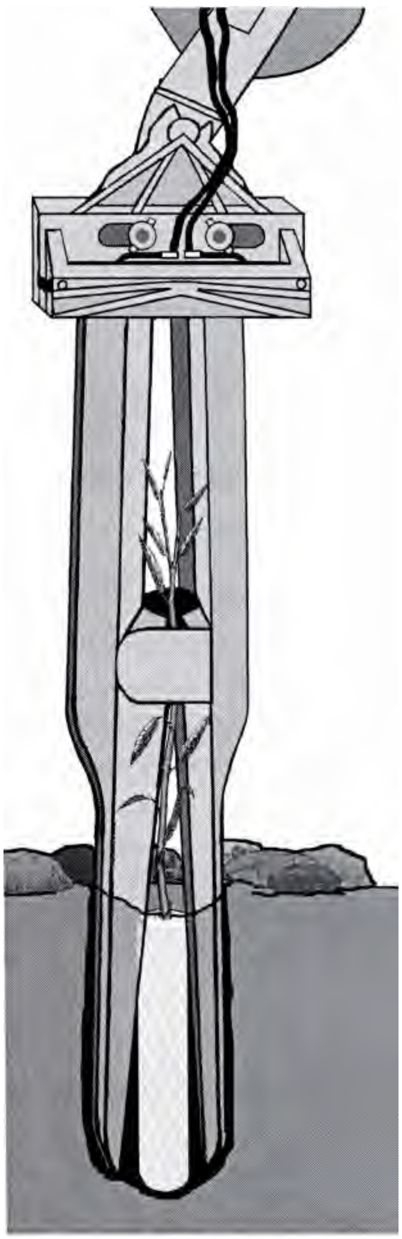

*Figure 5 - Target plant materials must consider th outplanting method. This "Expandable Stinger" i hydraulically-powered and can outplant containers o cuttings into difficult locations including rip-rap roc structures along waterways (modified from Steinfel and Landis 2001).*

## Improving the Quality of Target Plant Materials

The target plant materials concept is not static but must be continually updated and improved. At the start of the project, the restoration project supervisor and the nursery manager must agree on certain specifications. This prototype target seedling or cutting must be verified by outplanting trials in which survival and growth are monitored for up to five years. The first few months are critical because plant materials that die immediately after outplanting indicate a problem with stock quality. Plants that survive initially but gradually lose vigor indicates poor planting or drought conditions. Therefore, plots must be monitored during and at the end of the first year for initial survival. Subsequent checks after 3 or 5 years will give a good indication of growth potential. This performance information is then used to give valuable feedback to the nursery manager who can fme tune the target specifications for the next crop (Figure 6).

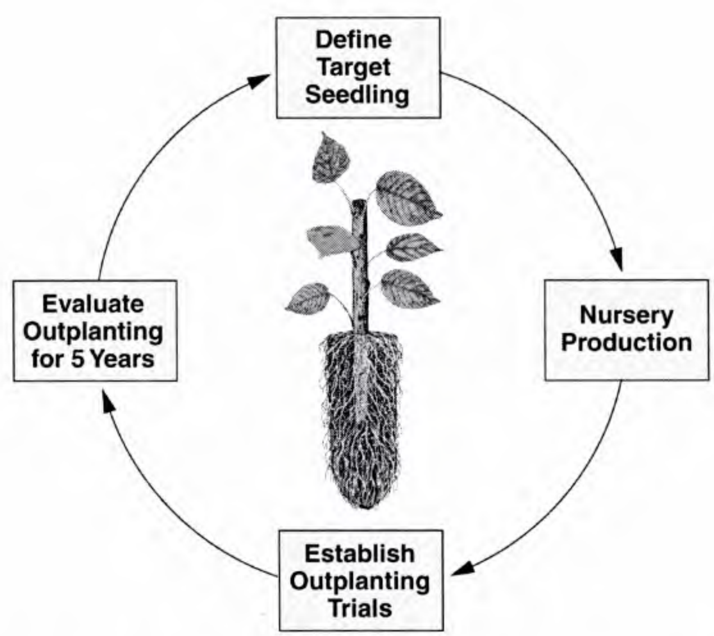


*Figure 6 - The target plant materials concept must be continually updated by outplanting performance.*

## Summary

The target seedling concept was developed to help stimulate and clarify communication between the forest seedling customers and nursery managers. Describing the ideal plant for a particular restoration project and following a series of sequential steps will also be a useful exercise for native plant nurseries and users. Instead of the traditional linear process which begins in the nursery, the target seedling concept is a circular feedback system where information from the outplanting site is used to define and refine the best type of seedling.

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# Propagation Protocol Database on the Native Plant Network

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## Abstract

The demand for native plants continues to increase but published information on how to propagate natives is extremely limited. A wealth of propagation knowledge and experience exists in native plant nurseries, but there isn't an easy way to share it. The Native Plant Network on the Internet offers basic propagation information as well as a searchable database of propagation protocols. An easy-to-use data form allows growers to submit propagation information as well as update it as new information becomes available.

### Key words

Nursery, seedlings, Internet, plant production

## Introduction

Forest and conservation nurseries are being asked to propagate an increasingly wide variety of native plants, from ferns and forbs to shrubs and noncommercial trees. Learning how to propagate this variety of plants can be a formidable challenge. For example, compared to species traditionally grown, native plant seeds come in a bewildering array of shapes and sizes that make them hard to collect, clean, and sow. Most native plant seeds also have some type or degree of dormancy and need special treatment before they will germinate.

Research is the traditional source of new technology, but few scientists are working on new native plant propagation techniques in the US, and most of that work

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is with threatened and endangered species. This problem can be traced to recent personnel downsizing as well as a lack of priority by research administrators. So, most new propagation techniques are being developed on-the-job by native plant nurseries but, unfortunately, this information is not being shared for several reasons. Obviously, private nurseries have a proprietary reason for not wanting to share their trade secrets. On the other hand, state and federal government nurseries that were a traditional source of nursery technology just don't have the time to document in writing what they know by experience. In addition, declining government budgets and fewer personnel makes sharing information a low priority. Recognizing this need, the Reforestation, Nurseries and Genetic Resources (RNGR) team of the USDA Forest Service came up with the idea of developing a system for sharing propagation protocols for native plants: the Native Plant Network.

## The Native Plant Network

**www.nativeplantnetwork.org**

The network currently consists of two parts: the Native Plants Journal and the Propagation Protocol Database. The network was begun as a cooperative agreement between the USDA Forest Service Cooperative Programs and the University of Idaho Forest Research Nursery in early 1999.

### Native plants journal

The journal, which we like Co describe as an *eclectic* forum for dispersing practical information about planting and growing native plants, is published twice each year in full color. Each issue contains scientific and practical articles, including plant production protocols. All previously published articles are in a searchable database on the Network.

### Propagation protocol database

Our focus is on the Propagation Protocol Database. A propagation protocol is a comprehensive procedure on the cultural details of growing a specific native plant—in other words, a recipe. A typical protocol is a detailed, step-by-step process that starts with target seedling specifications and contains information on how to collect seeds or cuttings; how to grow the plant in a nursery; how to harvest the plants, seeds, or cuttings; and how to outplant them (Landis et al. 1999, Landis and Dumroese 2000).

The basic idea was to publish propagation protocols on the Internet using a standard format. Internet publishing has several advantages: first, it is relatively inexpensive compared to trying to publish in hard copy; second, it is quick; and third, computer files are easy to access and update. We are also coordinating with the USDA-Natural Resources Conservation Service to cross-link our protocols with their PLANTS database (http://plants.usda.gov).

As of I December 2001, the database contained almost 1300 protocols with more than 100 plant families represented. Almost 100% of the protocols have been added by government agencies (Table 1). About 400 more protocols are in the process of being added.

Propagation protocols are organized by genus, species, species binomial, state or province, product type (container, bareroot, etc.), organization type, and nursery or company. This organization is necessary because one species can be propagated by several different methods. Also, a wide ranging species may have several ecotypes that have different cultural requirements. For example, the database contains five protocols for quaking aspen *(Populus tremuloides).* One short protocol identifies the seed dormancy mechanism and suggested presowing treatment for aspen (Baskin and Baskin 2001). At the Glacier Park Native Plant Nursery in Montana, aspen is propagated by either seeds (Luna et al. 2001) or root cuttings (Johnson et al. 2001) collected in the wild. Seed propagation is also the method used at the Colorado State Forest Service Nursery but the cultural techniques are significantly different (Moench 2001). At Los Lunas Plant Materials Center in New Mexico, quaking aspen is propagated using root cuttings from stock plants held at the nursery (Dreesen 2001, Dreesen and Harrington 1999). By providing a variety of protocols, novice growers can chose several propagation options and select the one that best matches their location and objectives.

**Table 1. Number of propagators by category and thei contribution to the total protocols in the Propagation Protocol Database on the Native Plant Network as of December 2001.**

| Propagator Classification | Number of Propagators | Protocols | Percentag of All |
|---|---|---|---|
| Private | | 12 | 1.0 |
| State | | | |
| | University | 1 | 25.0 |
| | State Nursery | 6 | 5.0 |
| Federal | | | |
| | USDA | | |
| | NRCS Plant Materials Centers | 15 | 23.0 |
| | National Forests | 1 | 2.5 |
| | Federal Nursery | 2 | 1.5 |
| | Other Forest Service | 2 | 1.0 |
| | USDI | | |
| | National Parks | 3 | 41.0 |
| Total | | 42 | 100.0 |

## Searching the Propagation Protocol Database

To search the database, just click on *Search the Protocol Database.* You can search by typing in a genus, species, binomial, Latin family name, by selecting a species from a drop down menu, state or province, organization type, company or nursery name, or various combinations of these parameters. Leaving all of the fields blank will generate a list of every protocol in the database. From the list of matches to your search, you may select particular protocols based on species, stock type, location, date of entry, and so on (Figure 1). One handy feature is the batch print function that allows you to accumulate and print several protocols at a time. Just place a check in the box next to the protocols of interest and they will be formatted so you may print them using the print command in your browser. Printed protocols are in a format that allows them to be three-holed punched for storage in a loose-leaf binder.

## Adding to the Propagation Protocol Database

### Register as a propagator

We strongly encourage professional and amateur plant propagationists to submit any propagation information that they may have. We have tried to make the process relatively easy and are continually updating the process to make it more friendly. The first step is to click on *Add/Edit Your Protocols* and register as a propagator. Registering will allow you to add multiple protocols without having to re-enter basic information like your name, address, and contact information. And, if at a later date you wish to update one of your protocols, you may access the file using your username and password. Growers are also encouraged to submit their nursery, company or agency logos which will be displayed whenever someone views your protocols.

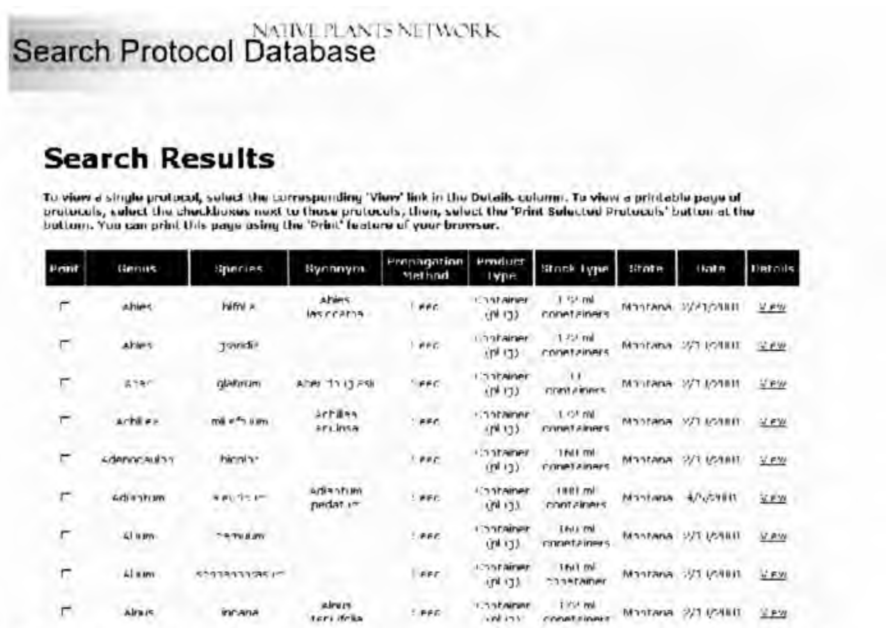


*Figure 1. A partial view of search results from a query for protocols from Montana. From this page, searchers may either view protocols one at a time by selecting View, or view multiple protocols by clicking the Print box of desired protocols and selecting the print function at the bottom of the search results. Multiple protocols are then displayed in a format suitable for printing using the print function of the web browser.*

### Entering a protocol

On the Network, we have provided an example of a completed protocol input form as well as a blank form. Many propagators print or copy the blank form to see what information is requested by the database. They can then compose the necessary information in a word processing program to ensure accuracy and easily cut and paste it to the protocol input form. Given the immense variety of plant types, nursery stock types, and propagation objectives, we realize a one-glove-fits-all approach is not realistic, but on the other hand a free-flow anarchist approach is not conducive to finding and using data. So, our intention is that the standardized form provides only a framework for adding protocols.

The main headings are fairly general and we encourage propagators to use subheadings under main headings when necessary to present their data. Folks familiar with hypertext language can insert their own formatting; others can use the help feature and hypertext format drop-down box for assistance. Some fields are required (for example, genus, species, family) but many are not. Don't worry—if you decide data is not needed in particular fields or you simply don't have that type of data, skip those fields. Blank fields will not be displayed on the protocol output form. Once a protocol is entered but before it is submitted, you may preview it for accuracy. If everything is correct, the protocol can be submitted to an approval queue where it will be checked for appropriateness of content before being added to the database. Protocols are generally approved within seven days and can then be found as part of the Propagation Protocol Database.

**Protocol Information**

Glacier National Park
Montana

| | |
|---|---|
| Family Scientific Name: | Pinaceae |
| Family Common Name: | Pine family |
| Scientific Name: | *Pinus ponderosa* Dougl. |
| Common Name: | Ponderosa pine |
| Species Code: | PINPON |
| Ecotype: | Ponderosa forest, North Fork of Flathead River drainage, Glacier National Park, Flathead Co., MT., 1000m elevation. |
| General Distribution: | *P. ponderosa* occurs in lower levels in the mountains and valleys, where rather dry, often in pure stands, from southern B.C. to Baja California, mostly east of the Cascades, occasionally west of the Cascades in southwestern Washington but more abundantly in Oregon and California, east to southeast B.C., Montana, the Dakotas and south through the Rocky Mountains to west Texas and northern Mexico. Its elevation range is 100 to 2700 meters. |
| Propagation Goal: | Plants |
| Propagation Method: | Seed |
| Product Type: | Container (plug) |
| Stock Type: | 172 ml conetainers |
| Time To Grow: | 7 Months |

*Figure 2. A partial view of propagation protocol from the nursery at Glacier National Park showing contact information and agency logo. Protocols from other organizations also provide active URLs to their websites. All protocol output displays with a complete citation so credit can be given to the authors.*

### Professional credit

We designed the database so credit goes where credit is due. The protocol input form allows the data entry person to list one or more authors for each protocol to ensure that proper credit is provided.

### Protocol output

When your protocol is viewed by someone, it appears in their browser with propagator information, organization logo, the protocol proper, and a self-generating citation that includes the authors and other necessary information for relocating the protocol (Figure 2). Again, the automatically-generated citation ensures credit goes to the developer(s) of the protocol. This citation should also be used whenever information in the protocol is referenced. Furthermore, you can add your organization's URL or email address to the database so viewers of your information are only a click away from your website, products, and services. For the private nursery manager, this can be a good marketing technique.

## Summary

The Native Plant Network is an excellent information resource for people who want to grow or use native plants. Propagation protocols offer an easy, yet comprehensive, way to share information on how to grow native plants. We hope that all propagators will use this new way to seek cultural information and share their propagation knowledge.

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# Restoration Strategies

## Native Plant Garden: Practices and Recommendations

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## Abstract

Native plant gardening has a long and complex history closely tied to English "wild gardening" and other gardening traditions. Native U.S. plants, including N.W. natives are already used worldwide. The history and traditions of ecological restoration, on the other hand, are rooted in scientific thought and tradition. Restoration ecologists can build on public interest in growing native plants horticulturally to increase support for restoration issues.

**Keywords**

ecological restoration, garden history, nature philosophy, native plant societies

## Introduction

"It is important that conservationists and restorationsists do not fall into the trap of ecological elitism, i.e. proposing the exclusivity of their own view of nature. Ecologists are surely the experts on ecology, but on nature there are many more" (Swart et al 2001).

Gardening is a venerable tradition, making "ancient forests" seem a truly new concept. Many histories of gardening exist on the bookshelves of individuals and libraries, featuring gardening traditions from Egypt, Greece, Rome, and China up to modern day gardening throughout the world. Penelope Hobhouse (1992) says, "The very stuff of the history of gardening, from ancient Egypt to the present day consists largely of plants that have been displaced and transplanted to new situa-

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tions . . . often being 'improved' in some respect along the way."

Today, public gardens representing their own regional flora exist around the world and plants from many nations are used as garden ornamentals internationally, including northwest native plants. In a sense, "native to the planet earth" has become applicable as a gardening concept, following the trend in generally weedy species like dandelions. With this trend come concerns about exotic species and their invasive potential, and generalized concerns about interchange between germplasm of native plants in nature and native plants or their relatives in garden or cultivated settings.

My intent here is to provoke thought and share some perspectives to aid further discussion and communication.

## History of Gardening in the Context of Gardening with Native Plants

Gardening is as old as civilization. The first gardens were most likely strictly utilitarian, such as growing food or medicinal plants close to home. The gardening traditions in the West (primarily Europe and it's former colonies) originate at or before 2000 BC, perhaps in Egypt, where art objects from tombs show gardens and images of gardens (Hobhouse, 1992). Western gardening patterns can be traced to many countries, including not only Egypt, but Greece, Rome, and the nations of Islam. Islamic gardens, for example, were developed in enclosed spaces in primarily desert climates, to be places of respite from the heat. They often included elaborate water "features" and shade trees to accomplish this goal. Our traditions of water in our garden spaces can be traced to Islamic gardens as reinterpreted in Europe.

Native plant gardening *per se* is easily traced to English gardens of the 19' and 20'h Centuries, which themselves can be traced back to naturalistic gardens of the Greeks (Hobhouse 1992). "By the 1830's," says Hobhouse, "most identifiable garden styles had already been tried, including the 'wild or native garden'."

A critical historic event is the development of the "wild garden" as an antithesis to formal Victorian schemes (Hobhouse 1992). In essence, the style involves planting many perennials and shrubs in an existing landscape or trees and shrubs, creating a "naturalistic" whole. This trend is still evident not only in native plant gardens but in any gardens with shrub and perennial borders. Wild gardening was made popular by William Robinson when he published a small book called simply *The Wild Garden* (Robinson 1870). Today, a good representative of this style of garden can be found at Portland's Berry Botanic Garden. In the 1930's the creator of this garden in the hills south of Portland, Rae Selling Berry, had already corresponded heavily with English gardeners who introduced the concept to her.

Interest in native plant gardening in North America is evident early on. By the mid-1700's native plants were being incorporated as garden ornamentals on the East Coast (Hobhouse 1992). At Monticello, Thomas Jefferson was experimenting with native plants in traditional landscape settings. For example, he was using the native Osage orange *(Maclura pomifera)* in a traditional European-style hedge (Hobhouse 1992). John Bartram sent seeds of many plant materials to Europe, including gentians *(Gentiana* spp.), cardinal flower *(Lobelia cardinalis),* golden rod *(Solidago* spp.) Turk's cap lily *(Lilium superbum)* and various southeastern *Rhododendron.*

An interesting trend in today's world is the cultivars of northwest native plants that are being reintroduced to us from England. The history of this is also fascinating, beginning with the exportation of many plants of this region by David Douglas (Hobhouse 1992). Douglas, trained as a gardener and collector traveled widely in the Pacific Northwest in 1824-1827. He was engaged by the Horticultural Society in England to collect plants here of horticultural merit and take them home to England. He is responsible for introducing to England his namesake plant Douglas fir *(Pseudotsuga menziesii)* in 1827, the noble fir *(Abies procera)* in 1830, as well as madrone *(Arbutus menziesii),* silk tassel bush *(Garrya elliptica),* and Oregon grape *(Mahonia aquifolium).* These are all used extensively in European horticulture.

Perhaps Douglas' most striking introduction, however, was the red flowering currant. "The flowering currant *(Ribes sanguineum)* was considered so important a find as to be itself worth the cost of the whole expedition (Hobhouse 1992). Many cultivars of Ribes sanguineum are now known in horticulture, most developed in England (See e.g., Phillips and Rix, 1989, which lists various varieties of *R. sanguineum,* including Atrorubens,' 'Brocklebankii,' 'King Edward VII,' and 'Pulborough Scarlet,' all of which were developed in England). Locally selected wild forms of R. sanguineum include a white form, reportedly collected in Oregon's Coast Range, and a form called "Elk River Red" a deep red form reportedly collected from southern Oregon (Jack Poff, personal comm.).

Today in the Pacific Northwest, native plant gardening has become increasingly common. As early as 1982, Arthur Kruckeberg (1982) in his *Gardening with Native Plants* book said, "Around the country, the urge to grow native plants in one's own garden or at the summer cabin is very much on the upswing." In the books second edition published in 1996 he says, "Fifteen years later a minor garden cult has become a major focus of American gardening." He credits the interest to nationwide environmental concern, water-saving consciousness, intrinsic appeal of one's local flora, and the increasing activity and visibility of native plant societies nationwide.

In yet another more recent trend "gardening for wildlife" as a way to attract birds and other animals using gardens, native plants are highly recommended. See for example, Link (1999) who says, "Over time, native plants have improved their ability to attract helpful animals such as pollinating insects and seed-dispersing birds. They have also become adept at repelling or surviving attacks from destructive organisms .. ."

One has only to type "native plant" into a worldwide web search to learn the overwhelming interest that exists both in the U.S. and abroad. One such search I undertook in October 2001 yielded more than 186,000 responses. When I checked the website for the North American Native Plant Society on October 16, 2001, it had recorded 12,609 "hits." The New England Wildflower Society, itself founded in 1990, lists 88 native plant societies and botanical clubs in North America and 13 botanical gardens featuring native plants prominently. Nearly all of these organizations, in turn, have their own web sites.

The New England Wildflower Society "promotes conservation . . . through horticulture, education, habitat preservation, and advocacy." Most other native plant societies, such as the one in Connecticut, actively promote gardening with natives as a conservation activity, although most also discourage wild collecting and some advocate local gene sources.

An interesting variant on the native plant society is that of specialty societies. The Society for Pacific Coast Native Iris is an example. The Society's web page features plentiful information about native iris, their biology, distribution maps, and gardening potential.

In addition, government sites from federal to local promote native plant gardening for conservation. A site of the Environmental Protection Agency (EPA) features native plant landscaping in the Midwest to improve the environmental and "bring a taste of wilderness to urban, suburban and corporate settings." The North American Native Plant Alliance is made up of 13 federal agencies and 178 private organizations banded together to promote and conserve native plants. Their web site includes information on gardening with natives and features links to other sites as well. Close to home, the city of Portland, Oregon offers "resources for seeds and native plants," includes listings of nurseries, references, plant lists and places to visit to learn more.

In some ways the "frosting" is the combined effort of Western Carolina University's Cooperative Extension Program, the U.S. Fish and Wildlife Service, the North Carolina Arboretum and others to do regional education. One of their featured projects includes a demonstration garden at a McDonald's restaurant off 140 near Asheville, North Carolina.

## Intersection of Gardening with Restoration: the Realm of Ideas

The scientific literature is replete with references on restoration. Many of these articles reflect their author's deep convictions about nature and restoration activities. Restoration is defined as "human intervention to recover nature's integrity which is considered to be threatened or even absent because of human activity . . . " (Swart, et al. 2001). Restoration ecologists often advocate a careful, stepwise approach, even while recognizing that this goal is sometimes impractical (e.g. van Diggelen et al. 2001). Societal involvement to maximum effect is also generally recognized.

Restorationists often express concern about seed sources, which leads them to be concerned that nearby garden plants might be "unwanted" source of germplasm. This can happen when seeds or pollen become dispersed by wind or animals a nearby wilder location. Such a view point is represented for example in Houseal and Smith (2000) who surmise that "large scale plantings of [cultivars] could negatively affect remnant plant communities through introduction of disease, contamination of local gene pool, or invasion of aggressive cultivars."

The other side of this "naturalistic" view is expressed by Schama (1996), who says, "Objectively, of course, the various ecosystems that sustain life on the planet proceed independently of human agency . . . But it is also true that it is difficult to think of a single such natural system that has not, for better or worse, been substantially modified by human culture ... It has been happening since the days of ancient Mesopotamia . . .And it is this irreversibly modified world, from the polar caps to the equatorial forests, that is all the nature we have."

Obviously we have transcended science and have entered into the realm of philosophy, or ideas. Since restoration ecologists make up only a very small part of our society, their ability to influence others must compete within a very broad idea context. Restoration ecologists work from a scientific perspective, and have a unique set of values as applied to nature. According to Swart et al. (2001) those values involve the ecological perspective, which often values "presettlement" vegetation. Other views of nature are "ethical," implying the duty of stewardship, and "aesthetic." Depending on the aesthetic being expressed, this value and complement or contradict "natural" or "ethical" values.

Swart et al. (2001) are also responsible for the introductory quotation to this paper. In context, they outline several general views of or approaches to nature. The "wilderness approach" is the one most advocated by scientists and includes nature as valuable for ecosystem function and as part of the food web. The second, which the authors describe as "Arcadian," values semi-natural but extensively used landscapes—sort of a cooperation between humans and nature. The Arcadian view, for example, incorporates historic sites into its view of important landscapes. The third view they entitle "Functional." Nature is everywhere and can be very useful, and adapts to how we use the land. In this view, even roadsides are valuable places and production-oriented forests, using principles of population dynamics, are perfect examples of how humans and nature "cooperate."

Landscape architect C. Baines (1995) takes a very broad functional view. Instead of seeing urban areas are concrete jungles, he sees urban grasslands in lawns and grassy areas, urban woodlands, urban forests, and wildflower meadows. He states that in Leicester, England, 25% of the city's land is in private gardens and another 25% in green space, including parks. He urges us not to forget the ecological value of this green space, and that the plants in urban areas and gardens also reflect our cultural heritage, a value that is in addition to ecological values.

If I were to characterize gardeners as a group, I would say that in general they are nonscientists, they enjoy whimsical plants and cultivars that capture their imagination of amaze their friends, their aesthetic is beauty, they love nature, they seek pleasure and serenity in their gardens, color is of high value, and they are motivated to garden as a hobby or for exercise. At the same time, I would characterize the restoration ecologist as someone who is serious, has a focus on species rather than cultivars, has a scientific outlook, whose aesthetic is the "natural," has a reverence (almost religious at times) for nature, whose favorite color is may be green, and who are motivated primarily by career goals and personal fulfillment. I would observe that both groups "want to do the right thing," which is good common ground, as is the abject love of plants.

## Opportunities for Working with Native Plant Gardeners

Our garden historian Penelope Hobhouse (1992) characterizes the 20th Century as the era of "Conservation in Gardening." She cites concerns about escaped exotics and the interest in gardening with natives, interest in conserving endangered plant species as well as vanishing cultivars as examples of this trend. This implies a receptive audience to conservation themes amongst gardeners. Already, we see this in the growing awareness of exotic invasive plants and their loss of desirability as garden ornamentals (personal observation). When English ivy can be listed as a noxious weed in Oregon, we have certainly made progress!

Baines (1995), quoted above in another context, adds, "The rhododendron walks, azalea days and daffodil festivals need to be celebrated as an integral part of urban woodland management, but there is a need to alert the captive rhododendron audience to the significance of native species too ... [Native plants] are a "fundamental platform of the diverse life-support system."

This new environmental awareness and attention to native plants provides an opportunity to enlist gardeners in restoration efforts. In doing so, we should be aware of the characteristics of gardeners articulated here, and be genuinely supportive of their efforts to use native plants in garden settings.

1. Recognize that gardening is an ancient tradition with its own history and mystique that is heavily tied to cultural evolution and identity
2. Promote gardening with native plants to help people connect to the natural world, because by doing so they will become advocates for restoration efforts.
3. Promote native plant gardening as a way to combat planting exotic ornamentals, particularly those that may become invasive pests.
4. Recognize that gardeners are motivated primarily by beauty and experimentation, while restorationists are motivated primarily by science.
5. Appeal to native plant gardeners through their desire to produce positive ecological results.
6. Create any recommendations to gardeners in a positive way to encourage their involvement and creative activity.
7. Use the web and other modern methods to talk to gardeners. They do not read the scientific literature.

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# Partnerships in Restoration and Education in Glacier National Park

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When native vegetation is disturbed by construction activities or impacted by overuse, the consequences include denuded ground, invasion by exotic plants, displacement of animals, and reduced ecological and aesthetic value. Glacier National Park faces continued and expanding pressure from such activities. Current visitation is nearly 2 million people annually. This increased visitation results in increased disturbance to park lands in the form of soil erosion and vegetation loss and increased impact from service-related construction activities such as road rehabilitation and utilities and maintenance repairs that involve ground disturbance. Over the past 12 years Glacier has developed a comprehensive restoration program to restore structure, function and plant diversity to these impacted areas. Indigenous plant material is used to maintain genetic integrity and native soils and plants are salvaged prior to disturbance and stored for replacement and replanting whenever possible. Seeds and cuttings are collected annually and propagated in the Park's native plant nursery and revegetation crews implement 30-40 restoration projects annually.

Since 1986 Glacier National Park has utilized partnerships in the planning, design, construction and revegetation of eight major road rehabilitation projects along the historic Going-to-the-Sun Road (GTSR). Using these relationships as a model we have expanded our partnerships to facilitate the continued success and expansion of our restoration program. These partnerships include the Federal Lands Highway Administration, local school districts, the US Forest Service, the Natural Resources Conservation Service, the Montana Conservation Corps, other national parks and collaborations between the various divisions in Glacier including Integrated Pest Management, Maintenance, Trails, Backcountry Rangers, Interpretation and Cultural Resources to name a few. These partnerships play an important role in the successful completion of our restoration objectives and expand in scope as

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we broaden our relationships with other agencies, educational organizations, and state and local programs.

Perhaps the greatest challenge in the restoration process is to insure that this work provides a lasting solution to resource degradation. To that end, Glacier has embarked upon an exciting cooperative relationship with several local schools to engage students in the Park's restoration program as advocates and practitioners. Utilizing funds provided through the Natural Resources Preservation Program and the Recreational Fee Demonstration Program, Glacier provided seed money to assist with the construction of two cooperative greenhouses at neighboring schools on either side of the Park. These greenhouses serve as laboratories for students while providing needed native plant materials for restoration projects. 'Parks as Classroom' grant funds allowed us to hire a seasonal education specialist to assist in the development of a workbook for teachers/park staff, that ties our educational activities to state required science curriculum. Through this Resources Stewardship and Education program, we provided classroom and field ecological and restoration activities to over 900 students last season. These students participated in site evaluation, monitoring, seed collection, plant propagation and restoration projects. In addition, we sponsored several student internships and developed plant production and restoration ecology curriculum for two tribal colleges. In conjunction with this curriculum development we provided actual classroom instruction for three environmental science classes throughout the school year, including Plant Propagation by Seed, Asexual propagation and Habitat Restoration.

We have been very fortunate to work with Tom Landis, National Nursery Specialist, and Kas Dumroese, plant physiologist for the US Forest Service to include our propagation protocols for over 225 species native to Glacier in their Native Plants Network Protocol Database. Our staff have worked closely with local Forest Service personnel to provide restoration planning, seed collection and plant materials production for rehabilitation work in the Bob Marshall Wilderness and other forest service lands adjacent to the park's boundaries. In addition, we have provided consultation to other agencies and National Parks through work details. We recently completed restoration plans for wetland mitigation projects on Salish Kootenai tribal lands in conjunction with the Federal Highways and the Montana Department of Transportation, as well as restoration planning for Rocky Mountain National Park.

We continue to value our long-term partnership with the Natural Resources Conservation Service and the Bridger Plant Materials Center in Bridger, MT. We have worked together under a cooperative agreement since 1986. Bridger staff provide valuable technical advise in regards to restoration planning and implementation as well as plant materials production, seed collection, cleaning, increasing, storage and distribution. We have come to rely heavily on these folks and credit our success to their continued involvement in our program.

One of our most beneficial relationships has been with the Montana Conservation Corps. Each year we utilize several crews throughout the summer to assist us in accomplishing a wide variety of projects that require diligence, dedication and tenacity to complete. Our projects this year were arduous in nature and took these crews well off the beat path up into remote high country locations. We are able to utilize this MCC program to address a backlog of resource projects that would remain uncompleted without their participation.

Through this process of creative partnering, we continue to provide for the preservation of the park as well as providing for visitor enjoyment. With the collaboration of various agencies, individuals, educators, students and peers, we are able to work together in an exchange of ideas, energies and resources that makes a positive and lasting improvement to our program and our public lands.

# Biology, Ecology, and Management of Invasive Plants

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## Abstract

Weeds are often not the cause, but symptoms of depleted ecosystem integrity_often legacies of on-going or past poor management practices. Unless ecological causes of weed invasions are understood in integrated, ecosystem-scale frameworks, weed management projects are often doomed to fail. It may be useful to consider weed management tools as either "ecosystem" tools or agricultural-scale tools. Ecosystem tools are minimally disruptive and have longer-term impacts on community development, but act slowly. Agricultural tools may be used on larger scales, but usually have highly disruptive, short-term effects on ecosystems.

Several lessons emerge from experiences managing weeds in their ecosystem contexts. These include needs to understand relevant ecological concepts and the importance of integrated approaches, to implement regular monitoring with provision for true adaptive management, and to pursue new technologies/strategies. There is also need for information clearinghouses where interested parties share weed management experiences and seek information resulting from others' experiences.

**Keywords**

weeds, invasive species, weed management, ecosystem management, *Phalaris arundinacea, Polygonum cuspidatum, Cytisus scoparius*

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## Introduction

Noxious weeds pose serious challenges to the management and restoration of ecosystems throughout the Pacific Northwest. Aggressive weeds displace desirable habitat and species diversity, often persisting in the face of active weed control efforts. Weed management is a large topic, covering myriad weed species, growing in many places, and involving many management strategies and tools. Further, effective weed management is strongly situational, paying close attention to the details of space and place. The limited time allotted this paper precludes detailed discussion of specific weed management situations or problems. However, a useful global approach might be to contrast a traditional weed management philosophy with an alternative philosophy that fits more snugly with the goals and objectives of watershed restoration. Such exploration may help you more fully understand the complexities of the weed infestations you might be working on in your specific restoration efforts. Thus, this paper reviews foundational considerations in managing some of the more widespread invasive weeds in the maritime Northwest. The "foundation" component focuses on understanding weed infestations in the contexts of the ecosystems in which they occur and of the key ecosystem processes they disrupt. Understanding these ecosystem contexts provides insights into possible management strategies for those weeds, and promises greater success in achieving restoration goals.

## Traditional Approaches to Weed Management

I'm a botanist and planner on a team of biologists and other scientists that manage the Cedar River Watershed, the main source of drinking water for 1.3 million citizens of Seattle and surrounding communities. The 91,000-acre Watershed is closed to unrestricted public access and managed for abundant, high quality water and fish and wildlife habitat. Contrary to how that may sound, the Watershed is far from pristine, having endured 150 years of timber extraction, road building, stream channelization and cleaning, mining, and urban development. Land management is guided by a Habitat Conservation Plan (developed under the Endangered Species Act), which is essentially a watershed restoration plan that directs us to repair past damages. Team members who manage the Watershed use working definitions of restoration to broadly guide their work. The definition I like is from Apfelbaum and Chapman (1997):

> ...a practical management strategy that uses ecological processes in order to maintain ecosystem composition, structure, and function with minimal human intervention."

One of my responsibilities on the Watershed management team is to set the direction of weed management in the Watershed by developing weed management plans, implementing weed management projects, monitoring, and so forth. In addition to being a botanist and planner, I am also a horticulturist trained within the traditional agricultural context of that discipline. I consider the traditional or "agricultural" approaches to weed management that I am familiar with and contrast those with this definition of ecosystem restoration. Two contrasts appear immediately. The first is that traditional approaches to weed management embed an implicit assumption that humans will always be involved in managing weeds, whereas a goal of restoration strives to eventually eliminate the need for human interventions. The second inconsistency focuses on ecosystem processes. Traditional weed management focuses strongly on the weed itself, purposefully removing it from the ecological context in which it occurs. Traditional weed management asks "How do I control this weed?"

We are familiar with the traditional tools used to answer that question: row-cropping or strip-cropping; intercropping; rotations; cover or competition crops; cultivation (e.g. disking); fallow; herbicides; mowing/chaining; predation (grazing; biocontrols); fire; and so forth. Some of these have a long track record, with a commensurately long legacy of adverse impacts to natural and social resources: Widespread Herbicide Use (contaminated surface/ground waters, altered soil floras, altered wildlife, estrogenic activity, threats to human health, etc.); Introduced Organisms/Pests (escaped biological controls, escaped seedings of exotic grasses etc.); and Large-scale

Habitat Modification (biodiversity loss, increased erosion/sedimentation, flooding/drought, etc.).

## Ecosystem Concepts in Weed Management

### What is the right question to ask? Or, what are useful ecosystem themes in weed management?

What happens if we stop asking "How do I control this weed?", and we start asking "Why do I have this weed?" Upon contemplation, answers to this question generate several themes, three important themes being the following:

1. Weeds are not the cause, but symptoms of depleted ecosystem integrity - often the legacy of on-going or past poor management practices. This is illustrated by historic overgrazing in the shrub- and desert-steppe of the Columbia Basin. Grazing destroyed the microbiotic crusts that were integral to the health of that ecosystem, leading to erosion, biodiversity loss, and catastrophic biological invasions.

2. Unless ecological causes of weed invasions are addressed and understood in an integrated, ecosystem-scale framework, weed management efforts are often doomed to fail. This is illustrated by frequently observed replacement of one managed weed with a non-managed weed, as in the case of bio-predated purple loosestrife *(Lythrum salicaria)* being replaced by reed canarygrass *(Phalaris arundinacea)*.

3. Ecological restoration takes time and operates on scales much different than the regulatory, political, and fiscal timescales that humans are used to. This is illustrated by formerly forested wetlands that are now swards of reed canarygrass. Placement of coarse woody debris initiates a key ecosystem process in these ecosystems that operates on a scale of centuries.

### Weeds compromise ecosystem integrity

If weeds are placed back into the *ecosystem* contexts in which they occur, we discover some enlightening facts about the biology and ecology of those weeds. In particular, one of the more enlightening areas of discussion is how weeds disrupt key ecosystem processes. Altered key ecosystem processes and services include the following, among others:

- nutrient cycling and carbon cycling (Scot's broom)
- sediment erosion and deposition rates (spartina)
- disturbance intensities and frequencies (cheat grass)
- evapotranspiration, water cycling, and hydroperiods (tamarisk; reed canarygrass)
- soil chemistry and soil biological processes (Russian knapweed)
- habitat availability for native plants/animals/other organisms (reed canarygrass)
- primary productivity (ryegrass)
- food web interactionslcharacteristics (trophic levels)
- genetic integrity (hawkweeds)
- resilience to disturbance (incl. biological invasions) (Scot's broom)
- biodiversity (spotted knapweed; cheat grass; reed canarygrass)

If this is what weeds do, can humans intervene specifically to interrupt these disruptions, effectively using ecosystem processes as weed management tools? Recent scientific research and field experiences confirm this is possible. Successful weed management may not be about managing individual species, but rather managing natural ecosystem processes essential to *ecosystem* integrity.

## "Ecosystem" Tools Contrasted with "Agricultural" Tools

It may be useful to consider weed management tools as either "ecosystem" tools or agricultural-scale tools. Ecosystem tools are minimally disruptive and have longer-term impacts on community development, hut act slowly. Agricultural tools may be used on larger scales, but usually have highly disruptive, short-term effects on ecosystems. What are some "ecosystem" tools that have been used to manage weeds?

- Allelopathy
- Competitive Exclusion (Planting, Mulching, Seeding, Shading)
- Microbiotic Soil Crusts

- Soil Health (Flora and Fauna)
- Downed/buried Wood (Feed the Carbon Cycle)
- Micro- and Macro-topography (De-leveling)
- Biodiversity
- Soil Chemical Properties (Ph/ nutrient Management)
- Predation (Biological Controls; Grazing)
- Hydroperiod Alteration (Flooding/drainage)
- Edge Effects (Planting Circles)

To illustrate the implementation of some of these "ecosystem" tools, I'll use macro-nutrient management (anti-fertilization), edge effects (planting circles), soil health, and downed and buried wood.

### Macro-nutrient management

Many weed species are known to be especially competitive in the presence of free (ionic) macro-nutrients such as nitrogen and phosphorus. Native plants are generally more competitive when soils are less fertile or lack free macro-nutrients. In disturbed ecosystems, nutrient cycling is altered to distinctly favor weeds. A technique for immobilizing free nutrients adds large quantities of carbon (such as compost or sugar). The soil fungi and bacteria increase on this energy source, immobilizing any available nitrogen and phosphorus. Desirable native species and their mycorrhizal associates are introduced during this 1 to 2 year window and benefit from reduced weed vigor. This process, sometimes called "anti-fertilization," is best used on soils that naturally have low fertility (such as sands or sandy-textured soils) and was first described by St. John (1988).

### Edge effects

The zone where two or more different plant communities come together is known as "edge." Edge environments are areas of ecological tension deriving from gradients of light, moisture, cover, and food. For those weed species forming monocultures (such as reed canarygrass), large-diameter planting circles or blocks have been used to successfully introduce "edge" (Antieau 2000). Herbicides are typically used to eliminate the weed from within a planting *circle.* Once the grass is dead, the blocks or circles are densely planted with desirable native vegetation such as willows, appropriate conifers, and/or deciduous shrubs. As planted areas of dense vegetation grow, their canopy begins to reduce the vigor and cover of adjacent areas of weeds, largely due to shading. As shaded weeds decline in vigor and density, desirable native plants become established and the planting circles "enlarge" into the weed infestation.

### Soil health

Biological soil processes have only recently come to light as integral *ecosystem* processes. Much is still unknown, but work by Elaine Ingham, Michael Amaranthus, and others has demonstrated the intimate and essential relationships that above-ground vegetation has with fungal, bacterial, and non-vertebrate soil inhabitants (Amaranthus 2001, Ingham and Molina 1991, Perry and Amaranthus 1990, USDA, NRCS 1999). Mycorrhizal associations have been shown to impart ecosystem resiliency to weed infestations (St. John 1999).

### Downed and buried wood

Until recently, the role of wood in ecosystems was poorly understood. We now know wood is integral to key ecosystem process because it houses and feeds fungal and animal organisms, provides critical moisture reserves, and becomes germination and growing substrate for natural (shade-tolerant) conifer regeneration (in wetter parts of the maritime Northwest). In forested ecosystems, canopy loss facilitates and supports the invasion of invasive herbaceous species through a variety of mechanisms. The absence of wood in these ecosystems continues to impede natural successional processes.

## Ecosystem Concepts Applied to Specific Species

### Reed canarygrass *(Phalaris arundinacea)*

Reed canarygrass is a typical disturbance-response species, often indicating past clearing, cultivation and leveling, altered hydroperiods, purposeful seeding, etc. However, it is also thought to be native in at least some parts of the Pacific Northwest (Antieau 2000). Infestations in formerly forested habitats are thought to dramatically alter soil flora. Long-term management themes focus on establishing forests that cast deep year-round shade (where appropriate, as in Puget Trough), getting wood back into/onto the soil, and introducing biodiversity. Innovative means of getting there include planting circles (edge effects), pole plantings, de-leveling (micro-topographic diversity), and coarse woody debris placement (carbon cycling; soil flora; plant succession).

### Japanese knotweed *(Polygonum cuspidatum)*

Japanese knotweed is increasingly a problem in wetter parts of the Pacific Northwest. This species is generally considered a disturbance-response species, following road-building, clearing, and cultivation activities. It is also known to invade flood-disturbed zones in riparian and wetland ecosystems. The species is suspected of altering soil flora in formerly forested areas. Long-term management themes focus on competitive exclusion (establishing tree canopies that cast deep shade during the growing season and getting wood back into/onto the soil. Innovative means of getting there include competitive exclusion using made materials (cardboard, carpetsÖ .) and then followed by dense plantings of desirable species. Untested ecosystem methods include micro-nutrient management (boron) and managing soil pH, but the environmental impacts of such approaches have not been well-examined.

### Scot's broom *( Cytisus scoparius)*

Scot's broom is often a typical indicator of soil disturbance (road-building, clearing, and cultivation), but is also known to invade grassland and oak ecosystems that have damaged microbiotic crust systems. Infestation is thought to lead to dramatically altered soil biota and altered nutrient cycling. Long-term ecosystem management themes focus on limiting seedling establishment by establishing plant canopies that inhibit germination/establishment (to wit, re-establish microbiotic crusts, i.e. competitive exclusion) or re-establishing fire regimes. Innovative means of getting there include re-establishing microbiotic crusts via "seeding."

## Conclusion

Weeds are often not the cause, but a symptom of depleted ecosystem integrity-often the legacy of on-going or past poor management practices. It is important to be able to assess the potential ecological causes of weed invasions, and then address and understand these in an integrated, ecosystem-scale framework. Successful weed management may not be about managing individual species, but rather managing natural ecosystem processes essential to ecosystem integrity.

Several lessons emerge from our experiences in managing weeds as components of ecosystems. These include needs to understand relevant ecological concepts and the importance of integrated approaches, to implement regular monitoring with provisions for true adaptive management, and to pursue new technologies and strategies. There is also need for information clearinghouses where interested parties can share weed management experiences and seek information resulting from others' experiences.

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# Techniques Used to Restore Puget Prairie Communities and Rare Plant Habitats

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## Abstract

Prairie restoration is an important land management practice for a number of agencies and landowners in the Puget Sound region. As prairie habitat has diminished, a significant number of plants and animals have become rare, necessitating restoration of this disappearing landscape. Prairie restoration involves controlling invasive shrubs, trees, and weeds, and propagating of plants to augment native prairie communities. Restoration methods such as determining the unit size, site preparation, species selection, and planting patterns are key components in the success of restoration projects.

Roemers' fescue is the dominant native bunchgrass in Puget prairies and is commonly planted in prairie restoration projects. Herbaceous species are selected based on their ability to thrive and functional role in the ecological community. Long term maintenance and control of scotch broom plants and seed banks are the keys to permanent establishment of restored prairies.

### Keywords

Roemers' fescue, Scotch broom, propagation, native species

## Introduction

This report summarizes some of the restoration activities that have occurred over the past 8 years within Puget trough grassland communities of Western Washington. Land managers consulted for this presentation are in involved in restoration

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and monitoring at Yellow Island (The Nature Conservancy), Fort Lewis prairies, Glacial Heritage (The Nature Conservancy), Scatter Creek Wildlife Area (WA Department of Fish and Wildlife), and Mima Mounds and Rocky Prairie Natural Area Preserves [WA Department of Natural Resources (DNR) Natural Areas Program (NAP)].

Puget prairies exist as remnants of a landscape that was once widespread in the lower Puget Sound region. Approximately 3% of the native prairie landscape remains, and a very small fraction of this is in excellent condition (Crawford and Hall 1997). Puget prairies exist primarily on very well drained glacial outwash soils, and have species in common with rocky bald grasslands and sandy meadow communities. Certain plant and animal species associated with Puget prairies have become extremely rare, prompting land managers to increase the quality and extent of protected prairie habitats through restoration.

## Restoration

Prairie restoration activities in the Puget prairies address species habitat needs and the control of exotic species. Some of these activities include: control of native and non-native woody species, non-native grasses and fortis, removing trees from areas that were previously occupied by prairie, restoring direct damage to soils/plant communities, and restoring habitat structure and plant species composition required by endangered and threatened species.

The outcome of various restoration activities depends on local site conditions, restoration goals, funding, and equipment/technologies available to the land manager. For instance, on state managed Natural Area Preserves, tree removal is accomplished primarily by helicopter, minimizing the use of ground equipment. Site managers at the Thurston County Glacial Heritage prairie are carrying out restoration work with light on-the-ground equipment traveling on pre-existing access roads. Fort Lewis and Glacial Heritage managers have explored the use of seed drilling equipment, while such equipment would be difficult to manage on the mounded topography of Mima Mounds NAP (Dunn, pers. comm. 2001, Randolph, pers. comm. 2001).

### Defining project goals

Prairie restoration goals vary considerably between sites and projects. When the goal is to exclude weeds and create protective ground cover, a dense single species planting may suffice. If the restoration of native species is not feasible, planting less expensive, non-invasive grass species may support a limited goal such as soil protection. For example, certain prairies used for Fort Lewis military training are rehabilitated to repair ongoing soil disturbance (Randolph, pers. comm. 2001).

Endangered animal species frequently favor a certain plant species or genus for their various life history needs. Consequently, the restoration goal might focus on increasing the numbers of a given plant species. For example, showy fleabane, *(Erigeron speciosus),* is being propagated for it's late season nectar values at Scatter Creek Wildlife Area (Dave Hays, pers. comm. 2001). Early blue violet, *(Viola adunca)* is being intensively restored to create butterfly larva feeding habitat on Long Beach Peninsula sand dune meadows. This supports an eventual re-introduction project for the Oregon silverspot butterfly (Hays 2000).

Successful restoration of a site for a rare plant species may require adequate gaps for the rare plant to colonize, and weed control to prevent competition for open space. Golden Paintbrush is a federally listed Threatened species that is a facultative root parasite, meaning it may benefit from the presence of a host plant (Wentworth 1997). By establishing native prairie plants in openly spaced patterns, the rare paintbrush has recolonized a number of restored microsites among typical companion plants.

Prescribed fire is frequently used in Puget prairie restoration because fire is a natural process that enhances many grassland communities and rare species (Tveten and Fonda 1999, Schuller 1997). This important tool can be detrimental in a restoration process, by increasing weedy species. Fire can also damage organic soils if heavy fuels exist such as shrubs, thick duff, or woody material. To achieve the goal of re-introducing fire without severely damaging soils and existing perennial prairie plants, site managers often remove excess woody material by hauling and chipping limbs, pile burning, etc.

A common management goal is to restore a site to the original condition or the condition of the adjacent grassland community. Replicating the complexity of the entire suite of species in a prairie plant community is a difficult task. Restoration practitioners will retreat from this goal after investing propagation efforts in species that repeatedly fail to germinate or survive. Instead, we often select a suite of forbs and minor grasses to accompany the dominant grass to approximate prairie structure and achieve an *economically* feasible restoration project (Davenport 1997).

## Scale and Implementation

The scale of prairie restoration projects has a relationship to the quality of the outcome for several reasons. If the intent is to replicate a good quality plant community, small-scale projects or large projects implemented in phases are used to ensure that the restored site receives the intensive maintenance required to be successful. The cost of long-term maintenance and phased designs should not be underestimated in grant and budget proposals.

Each site has unique characteristics that influence the size of each restoration "unit." The type and abundance of invasive species present must also be factored into the scale and cost of the project. Aggressive weeds may limit the area that is practical as a restoration unit. Other important factors that need to be considered for the successful maintenance of a restoration project are: the ease of access for maintenance activities, whether herbicides or manual weed control methods will be used, and the ability of project staff or helpers to identify native plants versus weeds. Although maintenance of the plants adds considerable cost, it is essential to a successful project. Without intensive maintenance activities, exotic species can compete with and overwhelm the newly planted plants.

A final consideration related to unit size is the potential benefit to the site ecosystem. Prairies and other grasslands are often composed of a subtle successional mosaic, supporting a variety of species. A phased design with a number of units may increase habitat and species diversity across the prairie landscape (Dunwiddie, pers. comm. 2001).

### Site preparation

The amount of site preparation varies depending on the type of restoration project. In the case of tree removal, it is necessary to first remove Douglas-fir trees and limbs (limbs can be chipped or burned), and then the "micro-site" that remains is further prepared for planting (raking, burning, etc.). Exotic species such as scotch broom are often treated effectively through mowing and/or herbicide treatment. However, if many scotch broom seeds exist in the soil, new seedlings may overwhelm the restoration site. Mowing followed by herbicide treatment of seedlings has created a reasonably suitable planting site for Roemer's *fescue* at Mima Mounds NAP Similarly, areas dominated by non-native grasses have been treated with Roundup and planted. A technique used at the Glacial Heritage site involves repeated tilling of areas dominated by non-native grasses and/or scotch broom to reduce competition and exhaust seed in the soil. These areas are intensively planted with Roemer's fescue (*Fatima* romeri), and additional broom cohorts are eradicated with a selective herbicide that does little harm to fescue (Dunn, pers. comm. 2001).

Another site preparation variation proven successful at Rocky Prairie NAP involves removing lower tree limbs and under-planting around existing trees. The trees were later removed after prairie plants were well established. As a result, weeds are less likely to invade a semi-shaded restoration plot. This method is effective where trees are widely spaced.

When possible, site managers should try to avoid removing thatch and duff thereby exposing bare soil on restoration sites. This organic material serves an important function as weed mulch and to conserve water for the seedlings. Occasionally it is necessary to reduce some of the organic duff layer to ensure that seedlings have full soil contact. Where a micro-site has been burned for cleanup and mineral soil is exposed, careful maintenance must be carried out to control weeds for the following two seasons.

## Species selection and propagation

A typical prairie restoration project involves collecting seed on site and growing plugs. Roemer's fescue is the dominant grass species used as a foundation for most prairie restoration projects. The seed is easily collected and propagated, and small plugs have a high rate of survival. Mature Roemer's fescue seed cleaned with an air separator frequently yields tetrazolium viability test results of greater than 90% viability.

Herbaceous species and other grasses are selected based on several criteria. For propagation these include: availability and ease of collecting seed, germinability, ability to grow into a reasonably well rooted plug within 6 months of planting, tolerance to transplantation, and habit in the field (does the plant compete and occupy space sufficiently to hold its own within one or two seasons?). Note that beauty and aesthetics are not criteria, so many lovely prairie flowers don't make the cut for projects. We also consider the ecological niche the plant is likely to fill. For instance, a mix of composites and other flowering plants provide a range of nectar and larval food sources for native prairie butterflies. Table I details a list of species successfully used for prairie restoration.

On state Natural Areas and Nature Conservancy managed sites, seed is collected and cleaned by a specially trained corps of volunteers (recruited by The Nature Conservancy). Experienced staff work with the volunteer team leaders to ensure the quality of seed produced. Plant propagation has been arranged through contracts and cooperative agreements with state and commercial tree nurseries, native plant nurseries, high school horticulture programs, and correctional facilities.

## Installation

Trained volunteers play a major role in getting plants in the ground in the spring, usually mid- March to early April. When the number of plants exceeds available volunteer help, "prairie crews" are sometimes contracted. Careful handling and quality transplanting work has a direct impact on seedling survival, especially of more sensitive herbaceous species.

Direct seeding and drilling of Roemer's fescue has been done on a more limited basis, primarily at the Glacial Heritage site. Early results have been promising, with 5 plants per square meter surviving in drilled plots after one year (Dunn, pers. comm. 2001). Fort Lewis prairie managers are also developing a program for drilling Roemers' fescue utilizing seed produced in seed plots (Randolph, pers. comm. 2001).

The pattern of planting can create unexpected results as the site develops structure. Roemers' fescue plugs often grow unusually tall in the second season. When fescue was interspersed with forbs in a regular pattern, we found that the less competitive forbs were overtopped and sometime eliminated by the second year. This problem was addressed by planting herbaceous species in large clumps or blocks, planting fescue in weedier areas and along the edge of existing prairie.

One hundred thousand Roemers' fescue plugs were installed at Mima Mounds in 1994, following a large tree removal project. These plugs were planted on approximately 2-foot centers. The plants had a high rate of

**Table 1. Species Successfully used for Prairie Restoration**

| Latin name | Common name | Features |
|---|---|---|
| *Festuca romeri* | Idaho fescue | Dominant bunchgrass |
| *Danthonia californica* | California oatgrass | Sub-dominant bunchgrass |
| *Luzula campestris* | Field woodrush | Hardy, fills unique niche |
| *Potentilla gracilus* | Slender cinquefoi | June flowering, |
| *Eriophyllum lanatus* | Woolly sunflower | June flowering, very sturdy |
| *Erigeron speciosus* | Showy fleabane | July-August flowering |
| *Achillea millefolium* | Common yarrow | June flowering |
| *Solidago spathulata* | Dune goldenrod | May flowering |
| *Microseris laciniata* | Cut leaf microseris | May flowering |
| *Viola adunca* | Early blue violet | April-May flowering |

survival, but the open spacing allowed a large influx of weedy species such as hairy cat's ear and velvet grass to take hold. There was no funding for weed maintenance of this large project, nor any provision to increase diversity by including herbaceous species. This experience prompted Natural Areas site managers to reduce new projects to a scale that allows for better maintenance, and to do research on the propagation of a wider range of species (Davenport 1997).

## Site Management Affecting Restoration

The greatest challenge affecting most of the restoration projects covered in this review is the management of non-native shrubs such as scotch broom and pernicious pasture grass species (Parker et al. 1997). Hairy cats-ear *(Hypochaeris radicata),* has also created problems in the Long Beach dune meadow restoration, Fort Lewis prairies, and in burned restoration areas at Mima Mounds NAP (Hays 2000, Tveten 1999, Schuller 1997). Ecologically important prairies that have serious scotch broom infestations include Fort Lewis prairies, Mima Mounds NAP, Scatter Creek Wildlife Area, and Thurston County-Glacial Heritage. Site managers have developed strategies for managing broom with varied success, depending on funds and consistent agency support.

The initial broom control strategy for Mima Mounds depended on the frequent use of prescribed fire. Beginning in 1992, large burns (> 100 acres) were carried out to control broom. Additional units were burned in 1993, 1994, and 1996. Issues developed which have subsequently limited options for burning, including: a rapid increase in home development around the preserve; severe fire seasons which precluded the use of prescribed fire; shortage of funds; concerns about the lack of recovery in butterfly species following burns; and reluctance on the part of DNR fire managers to take on the risk of burning under the above conditions. Young broom plants usually survive burns in areas of low fuels, limiting the utility of fire as a broom control tool.

Over the last five years, broom at Mima Mounds NAP has been managed through targeted mowing, both by hand and with tractor mounted brush hogs. A negative side effect of mowing is that survivors develop into tough, multiple-topped shrubs. The only viable permanent control is to treat these plants with herbicide or extract them. In high quality areas of limited infestation, work crews and volunteers have hand pulled broom. These methods have gradually increased the high quality, broom free areas, while controlling seed production and spread in more heavily infested areas.

A similar but perhaps more intensive scotch broom control strategy is in place at Thurston County Glacial Heritage (a 1050 acre site), matching the control technique to the age and density of the broom, utilizing mowing, hand pulling, fall herbicide application, and herbicide wiping. A large area formerly described as "acres of solid broom" is now 25% broom free, with 2/3 of the area supporting prairie with broom under 1/2 meter in height. Site managers also conducted a 12-acre prescribed burn at Glacial Heritage in 2001 (Dunn pers. comm. 2001).

Scotch broom control strategies have a direct relationship to the success of native species restoration on prairies affected by broom infestation. Many projects have been compromised by the rapid re-invasion of broom. The high priority of controlling broom and other exotics may require postponement of expensive native plant propagation projects. Reducing a scotch broom seed bank is time consuming, but such efforts prior to plant installation are worthwhile.

## Conclusions

Developing well-defined goals, which identify the key species, habitat structure, and appropriate scale of a project, enhances prairie restoration. Considerations of scale and unit size are important for a number of reasons including successional diversity and realistic maintainability. Potential problems with weed invasions should be anticipated and control actions incorporated into plans prior to beginning the project. Species used for restoration should be selected based on a number of factors including habitat value, ease of seed collection, germinability, greenhouse suitability, vigor, transplant success, and long-term persistence. High standards in plant handling and transplanting, and later maintenance of planted areas, will greatly influence survival. Restoration may be delayed until persistent weed seed banks are suppressed (or released and controlled) to levels that will not severely compromise project success.

As prairie and grassland managers gain experience with restoration, our methods continue to improve and develop refinement. We have adjusted the scale of each phase to fit our funds and ability to provide maintenance, and learned to advocate for long term needs for restoration. It is particularly encouraging to be part of this network of managers dedicated to prairie conservation and restoration, whose experience and shared knowledge made this report possible.

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# Bio-structural" Erosion Control: Incorporating Vegetation in Engineering Designs to Protect Puget Sound Shorelines


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## Abstract


The conventional engineering approach to slope stabilization and erosion control usually relies solely on structural components. Vegetation is rarely included in engineering designs, though occasionally it is treated as incidental landscaping. Though the benefits of vegetation's role in erosion control are poorly understood within the engineering community; the value of vegetation in controlling erosion and reducing shallow mass wasting is well documented.

While engineered structures provide immediate stabilization and erosion abatement, they become progressively weaker over time and do not adapt to changing site conditions. Vegetation, though ineffective when first established, becomes progressively more effective, adaptable, and self-perpetuating over time. Vegetation also improves water quality, reduces storm water run-off, enhances wildlife and fisheries habitat, improves aesthetics, and reduces noxious weed establishment.

A "Bio-Structural" approach to erosion and slope stability problems; i.e., incorporating planned vegetational elements in engineering designs, can be less expensive, more effective, and more adaptable than purely structural solutions. Vegetation should be used in conjunction with geo-textiles and engineered structures whenever appropriate and practical.

Vegetation selected for "Bio-structural" design elements should be native whenever possible. Plants chosen should also be appropriate to the site, have wide adaptability, favorable spread and reproductive capability, superior control value, roots of high tensile strength, and be available commercially.



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**Keywords:**

Shoreline restoration, slope stabilization, sedimentation control, noxious weed control, biotechnical methods.

## Introduction

Surface erosion and mass soil losses from landslides are of great concern to land managers. Accelerated erosion and slope instability can be caused or exacerbated by human activities. Increased erosion can cause adverse cumulative watershed problems by increasing sedimentation, degrading water supplies, reducing forest productivity, destroying anadromous fish habitat, and degrading other critical environmental functions. Mature structurally and floristically complex plant communities significantly reduce surface erosion and contribute greatly to maintaining slope stability.

The conventional engineering approach to slope stabilization and erosion control usually relies solely on structural components. Vegetation is rarely included in engineering designs, though occasionally it is treated as incidental landscaping. Though the benefits of vegetation's role in erosion control are poorly understood or appreciated within the engineering community, the value of vegetation in controlling erosion and reducing shallow mass wasting is well documented. The use of vegetation and biotechnical measures should be incorporated into engineering designs early in the planning and design phases of a project.

## Role of Vegetation

"The loss or removal of slope vegetation can result in either increased rates of erosion or higher frequencies of slope failure. This cause-and-effect relationship can be demonstrated convincingly as a result of many field and laboratory studies reported in the technical literature." (Gray and Sotir, 1996). Vegetation also improves water quality, reduces storm water runoff, enhances wildlife and fisheries habitat, improves aesthetics, and reduces noxious weed establishment.

### Benefits of vegetation in preventing surficial erosion

Protocols have been developed to describe the factors that are instrumental in vegetation's effectiveness in limiting surface erosion. Wischmeier (1975) identified three major subfactors: (I) canopy, (II) surface cover, and (III) below surface effects. Dissmeyer and Foster (1984) modified and made additions to the earlier work to adapt it to forest conditions. The basic forest sub-factors useful in applying the modified universal soil loss equation (USLE) include ground cover, canopy, soil reconsolidation, organic content, fine roots, residual binding effect, and on-site storage of water.

Gray and Leiser (1982) provide a summary of the major effects of herbaceous and woody vegetation in minimizing erosion of surficial soils. They include:

- Interception — foliage and plant residues absorb rainfall energy and prevent soil compaction.
- Restraint — root systems physically bind or restrain soil particles while above-ground residues filter sediment out of run-off.
- Retardation — above-ground residues increase surface roughness and slow run-off velocity.

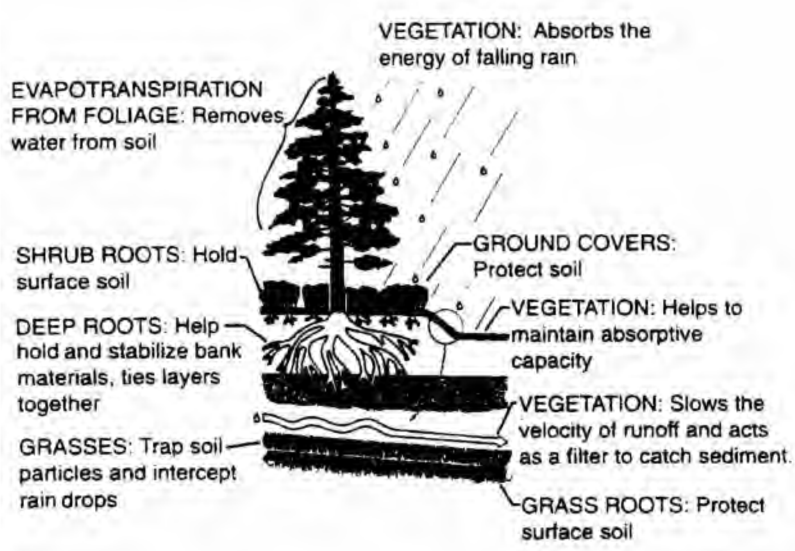


*Figure 1.*

- Infiltration — roots and plant residues help maintain soil porosity and permeability.
- Transpiration — depletion of soil moisture by plants delays onset of saturation and run-off.

Greenway (1987) notes that "roots reinforce the soil, increasing sod shear strength", "roots bind soil particles at the ground surface, reducing their susceptibility to erosion," and "roots extract moisture from the soil..., leading to lower pore-water pressures." Several layers of vegetation cover, including herbaceous growth, shrubs, and trees, multiply the benefits discussed above.

## Benefits of vegetation in slope stabilization

A substantial body of credible research concerned with vegetation and slope stability exists. Most of the literature supports the contention that, in the vast majority of cases, vegetation helps to stabilize a slope (Macdonald and Witek, 1994). As Gray and Leiser (1982) remark, "The neglect of the role of woody vegetation (and in some instances its outright dismissal) in stabilizing slopes and reinforcing soils is surprising." Their summary of beneficial influences of woody vegetation follows:

- Root Reinforcement — roots mechanically reinforce a sod by transfer of shear stresses in the soil to tensile resistance in the roots.
- Soil moisture modifications — evapotranspiration and interception in the foliage limit buildup of soil moisture stress. Vegetation also affects the rate of snowmelt, which in turn affects soil moisture regime.
- Buttressing and arching — anchored and embedded stems can act as buttress piles or arch abutments in a slope, counteracting shear stresses.

Greenway (1987) notes "that as vegetation is removed from a watershed, water yield increases and water table levels rise." Permanent loss of vegetation cover, or replacement by ineffective vegetation, increases soil saturation and surface water run-off. Vegetated watersheds exhibit lower peak flows, lower total discharge volumes, and increased lag-time between rainfall and run-off than do watersheds where effective vegetation has been removed (Figure 2).

## Limitations of vegetation

While undisturbed mature native vegetation on slopes provides erosion control and slope stabilization benefits, disturbed or degraded sites undergo continual erosion, and may not establish an effective cover. Vegetation alone may be relatively ineffective where hydrologic influences, fluvial processes, or wave attack repeatedly interrupts natural plant succession and favors less effective species. Competition by invasive, exotic plants such as Himalayan blackberry can also retard or preclude natural establishment of effective vegetation. Hydro-seeded grasses are often ineffective in minimizing surface erosion subsequent to construction and additional expenditures are necessary to repair slopes damaged by rills and gullies. Grass provides virtually no slope stabilization benefits. Grassed slopes provide negligible storm water filtration ben-

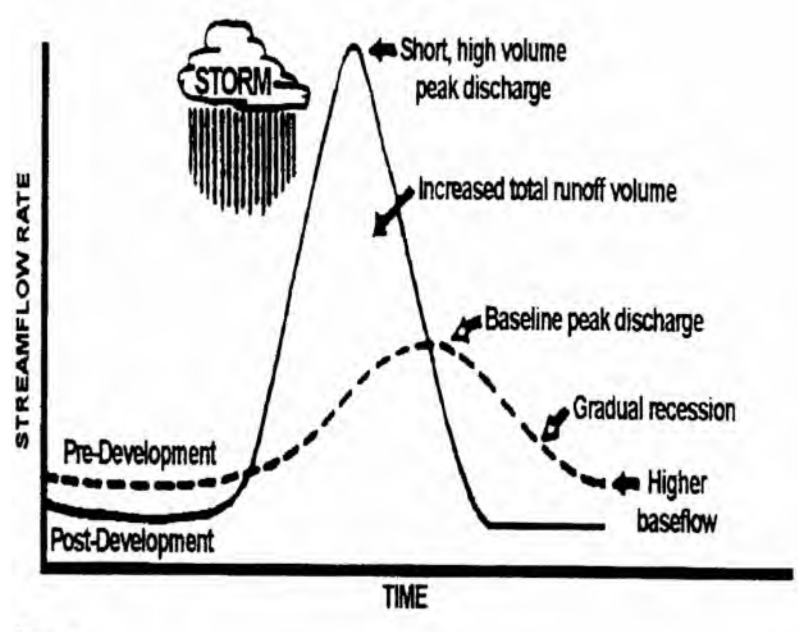


*Figure 2.*

efits compared to native ground covers. Grasses are ineffective in discouraging the establishment of undesirable invasive plants.

Vegetation alone is ineffective in the presence of deep-seated instability and active mass wasting. A disturbed or modified site must be stable enough to allow establishment and development of an effective plant community, often for as long as JO years.

## Engineered Measures Provide Stabilization, but at a Cost

Where accelerated erosion, slope destabilization, and landslides have occurred, engineered measures suited to the geomorphologic conditions are often necessary to stabilize the site. Engineering solutions aim to both reduce the influences of destabilizing forces and physically arrest slope failure and surface erosion. There are four basic methods used to improve slope stability:

- Unloading the head of the slope
- Ground and surface water regime modification
- Buttressing the toe of the slope
- Shifting the position of the potential failure surface

The specific measure or combination of measures employed is dependent upon a wide variety of complex factors, including geomorphology, hydrology, slope, climate, failure type, and topography. Macdonald (1994) provides an excellent written and photographic description of commonly employed conventional structures and hydrologic control measures in the Puget Sound region. Most engineered solutions result in significant incidental slope modification and environmental impacts. Toe stabilization on marine and riparian shorelines, such as riprap, are disruptive to nearshore habitat and affect coastal processes. Slope stabilizing measures, such as stepped crib walls, change slope geometry. Drainage measures, such as horizontal drain piping, alter both slope and down-gradient hydrology.

While engineered solutions effectively provide immediate stabilization and erosion abatement, they also cause environmental impacts to public resources. Removal of vegetation is common during construction of structures. Loss of vegetative cover often initiates soil degradation causing the site to become less productive. Conventional erosion control and revegetation efforts subsequent to construction are often ineffective and fail to adequately protect bare soil from incidental surface erosion and adjacent slope impacts. Products such as "jute" mats are ineffective in reducing surface erosion or encouraging the establishment of effective vegetation.

Engineering measures deteriorate over ti me, becoming progressively less effective or failing entirely. Adjacent slope movement can involve structures and impair their effectiveness. Where revegetation efforts consist merely of hydro-seeding or sod, ineffective vegetation is likely to become established, providing few of the benefits discussed above. If desirable effective vegetation is not deliberately incorporated into engineered measures, slope problems may become recurrent over the long term.

## Bio-Structural Approach

A Bio-Structural approach to erosion and slope stability problems (i.e., incorporating planned woody vegetational elements in engineering designs) can be less expensive, more effective, and more adaptable over the long term than purely structural solutions. Revegetation and biotechnical measures should be used in conjunction with geotextiles and engineered structures whenever appropriate.

Bio-structural erosion control and slope stabilization includes the measures known as soil bioengineering and biotechnical slope protection. As Gray and Leiser (1982) state, "both biological and mechanical elements must function together in an integrated and complementary manner.

The following is a very brief summary of important factors to consider when incorporating planting and biotechnical measures in engineering designs.

### Define objectives

What do you hope to achieve by incorporating vegetation in an engineering design? Some common objectives and goals include the following:

- Erosion control (rilling and gullying)
- Slope stabilization (marine, riparian, terrestrial)
- Restoration of pre-project vegetative cover
- Creation of wildlife and fisheries habitat (cover, food, and shade)
- Stormwater management (reduction of run-off and sedimentation)
- Aesthetic enhancement (landscape restoration)
- Regulatory mitigation (buffer enhancement)
- Reducing invasive plant establishment

### Suitability of the site

What are the physical environmental, and social characteristics of the site? Is revegetation possible and desirable? Each site is different and unique. Failure to consider pertinent factors often results in failure of biotechnical and planting efforts.

#### General Physical Characteristics:

- Topography
- Soils
- Slope
- Hydrology
- Aspect
- Geomorphology
- Climate

#### General environmental characteristics:

- Wind
- Salt (spray, tidal)
- Soil moisture and productivity
- Sun/shade conditions
- Precipitation (rain, snow, fog)
- Presence of invasive exotic plants
- Flooding and/or inundation
- Potential animal impacts

#### Social considerations:

- Offsite influences (drainage, invasive plants)
- Land use regulations
- View constraints
- Conflicting objectives (view vs. erosion control)

### Project design

It is imperative that planting and biotechnical measures be incorporated into the design from the project's inception. Vegetation should be considered integral to design rather than incidental. A team approach from first reconnaissance and feasibility through final construction will assure a successful project. Vegetational and engineering measures need to be coordinated to be effective. Common components of such projects may include structural, geotextile, biotechnical, and planting measures. Communication between project team members will minimize disruption to construction schedules and prevent other potential problems. Installation of vegetational measures often needs to be coordinated with mechanical structures and groundwork efforts. This is especially important where riprap or other slope-face stabilization measures are planned.

### Vegetation component of design

Every effort should be made to understand the specific constraints and opportunities of the site and project. Reference sites adjacent to the project should be surveyed to identify desirable species and plant communities for erosion control, slope stabilization, and wildlife and fisheries habitat value. If bioengineering measures are to be used; survey local areas for suitable plant materials for cuttings. Note any significant disease or insect problems. Determine if undesirable plant seeds will be a problem if existing project topsoil is to be used. Mulch or geotextile may be needed to reduce plant competition with new plantings. There are no "cookbook" plant lists or generic solutions. An inappropriate plant or biotechnical measure in the wrong place will compromise the project's effectiveness and waste money. Micro-site factors may need to be considered on project sites with varying slope, aspect, hydrology, and soils. All the factors listed previously regarding physical, environmental, and social characteristics should be specifically considered in plant and biotechnical measure selection.

Species selected should have the following attributes:

- Native to the area
- Appropriate to the site (e.g. salt tolerant, drought hardy)
- Have a wide biologic amplitude of adaptability
- Favorable spread and reproductive capability

- Superior erosion control value
- Excellent root spread and strength
- Be commercially available in adequate numbers or able to be contract-grown (1-2 year lead time).

Plant materials are available in a variety of stock types. Use of cuttings, bare-root stock, planting tubes, containers, or other types are all common. The type of plant stock selected will be dependent on various project-specific factors. These include planting season, site characteristics, plant availability, and soil type. Seeding of native woody vegetation is seldom practical or effective.

### Additional planning issues

Site preparation is a crucial element in planting or biotechnical projects. Eradication of undesirable species from the planting site and topsoil seed bank is critical. On sites with harsh exposures or droughty sites, irrigation may be required. The use of geotextile fabric may provide multiple benefits, including immediate erosion control, control of competing vegetation, and conservation of soil moisture. Animal damage protection for new plantings is often necessary to reduce losses.

### Monitoring, maintenance, and replacement

Many planting and biotechnical projects fail from neglect. Vegetative measures require care during the establishment period, from one to three years after installation. Contingency plans, and funds to implement them, should be part of project specifications. Vegetation measures are weak, ineffective, and vulnerable when first installed, but become progressively stronger, more effective, more adaptable, and self-perpetuating over time. If proper establishment, monitoring, and maintenance measures are undertaken subsequent to installation, the site should be self-sufficient after the third year.

#### Some monitoring elements to assess include:

- Mortality (replace dead plants)
- Damage (animal, insects, disease, vandalism)
- Wilting (check soil moisture regime)
- Trampling (human, animal)
- Adequate growth (to achieve coverage and effectiveness)
- Competing vegetation (control or eradication indicated)
- Erosion or hydrologic damage

#### Important maintenance efforts include:

- Replant as necessary to maintain stocking
- Irrigate as necessary
- Remove undesirable competing vegetation
- Protect plants from animal damage (browsing, trampling, etc.)

## Conclusion

Extensive clearing, grading, and slope modification are concomitant impacts of conventional erosion control and slope stabilization projects. Revegetation measures are often only an incidental component and are inadequate or ineffective, leading to the establishment of undesirable, invasive exotic plants subsequent to construction. Sedimentation of drainage facilities and adverse impacts to water quality, as well as degradation of fish habitat, are often unintended consequences. Existing mechanical best management practices and engineered hydrologic controls can be ineffective in mitigating increased and cumulative storm water impacts.

The recent listing of several salmonid species under the Endangered Species Act has focused attention on the importance of maintaining effective, native vegetation cover and minimizing impervious surfaces.

If native, woody vegetation planting and successful establishment becomes a routine objective of engineering plans and projects, then many of the adverse impacts and effects noted above will be significantly reduced.

Potential applications include slope stabilization, road and right-of-way, marine shore protection, and stream projects. Restoring the most valuable and effective plant communities on construction sites would also reduce future maintenance costs, reduce long-term erosion and landslide rates, improve wildlife and fish habitat, improve water quality, and help to maintain the aesthetic features synonymous with our region. While individual projects may have a relatively small benefit, the cumulative beneficial impacts are potentially enormous.

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# Native Shrubs as a Supplement to the Use of Willows as Live Stakes and Fascines in Western Oregon and Western Washington

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## Abstract

In the Pacific Northwest USA, willows *(Salix* spp.) are the primary species used for soil bioengineering and related streambank protection measures, including live stakes and fascines. Previous work also demonstrated satisfactory application of redosier dogwood *(Corpus sericea* var. *occidentalis)* and Douglas spirea *(Spiraea douglasii).* However, other native shrubs that root readily from dormant hardwood cuttings have not been well evaluated, if at all. Therefore, the purpose of this work is to test additional species for their ability to root from older wood and perform as live stakes and fascines.

Greenhouse experiments illustrate that snowberry *(Symphoricarpos albus),* Pacific ninebark *(Physocarpus capitatus),* and black twinberry *(Lonicera involucrata)* can root as well or better from three year versus one or two year old wood. Therefore, they should have good potential as live stakes. In contrast, salmonberry *(Rebus spectabalis)* rooted well from first year wood but more poorly from older stems. It appears to have less potential. Secondary results indicated no apparent benefit from Wood's rooting compound (IBA+NAA) and detrimental effects from bottom heat (75°F) for all four species.

In addition to greenhouse trials, these and other native shrubs are under evaluation at four streambank sites, two in western Oregon and two in western Washington. To date, snowberry, salmonberry, ninebark, and twinberry are performing successfully as live stakes and/or fascines at one or more of these locations. It

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appears all four could be used as supplemental species for soil bioengineering, and may have special application to sites less suitable for willows (i.e. shaded or summer dry environments). Ecotype, site factors, quality of stock, installation technique, and handling can substantially affect results. While unlikely to outperform willows, these species provide options for improving habitat diversity.

## Key words

Native shrub, soil bioengineering, live stake, fascine, *Symphoricarpos albus, Lonicera involucrata, Rubus spectabilis, Physocarpus capitatus*

## Introduction

It is widely know that most native, riparian willows *(Salix* spp.) in the Pacific Northwest USA root easily from dormant hardwood stock, including older wood, allowing for their successful use in soil bioengineering practices such as live stakes, fascines, or brush mattresses. While willows are the mainstays of these stream and shoreline protection measures, native shrubs that root easily (from hardwood cuttings) may provide restoration alternatives, improve habitat diversity, and perform as well or better in shade or other conditions less suitable for willows.

Live stakes, more so than fascines, require that a species root easily from branches three years of age or older. The stem must be old and sturdy enough to withstand being tapped or "pounded" into the ground. Previous rooting trials indicate that black twinberry *(Lonicera involucrata),* Pacific ninebark *(Physocarpus capitatus),* snowberry *(Symphoricarpos albus),* and salmonberry *(Rubus spectabilis)* are among those native Northwest shrubs with the highest potential for use in soil bioengineering (Darris et al. 1998). Willows, redosier dogwood *(Cornus sericea* spp. *occidentalis),* black cottonwood *(Populus balsamifera* var. *trichocarpa)* (King County DNR undated), and Douglas spirea *(Spiraea douglasii)* (Darris and Flessner 2000) have already proven to be fair to good candidates. While other potential species are found on national and regional lists (Bentrup and Hoag 1998, Goergia Soil and Water Conservation Commission 1994, King County Dept. of Public Works 1993, USDA-NRCS 1996) their actual performance is not always well tested or documented. Therefore, the purpose of this work is to conduct studies and demonstrations that evaluate the ability of select western Oregon and western Washington native shrubs to root from older wood and perform as live stakes and fascines under actual streambank conditions.

Figure I (USDA-NRCS 1996) illustrates the soil bioengineering practice of "live fascines", the method most commonly used in the evaluations. In this example, two rows of fascines (wattles or bundles 6-8" in diameter)

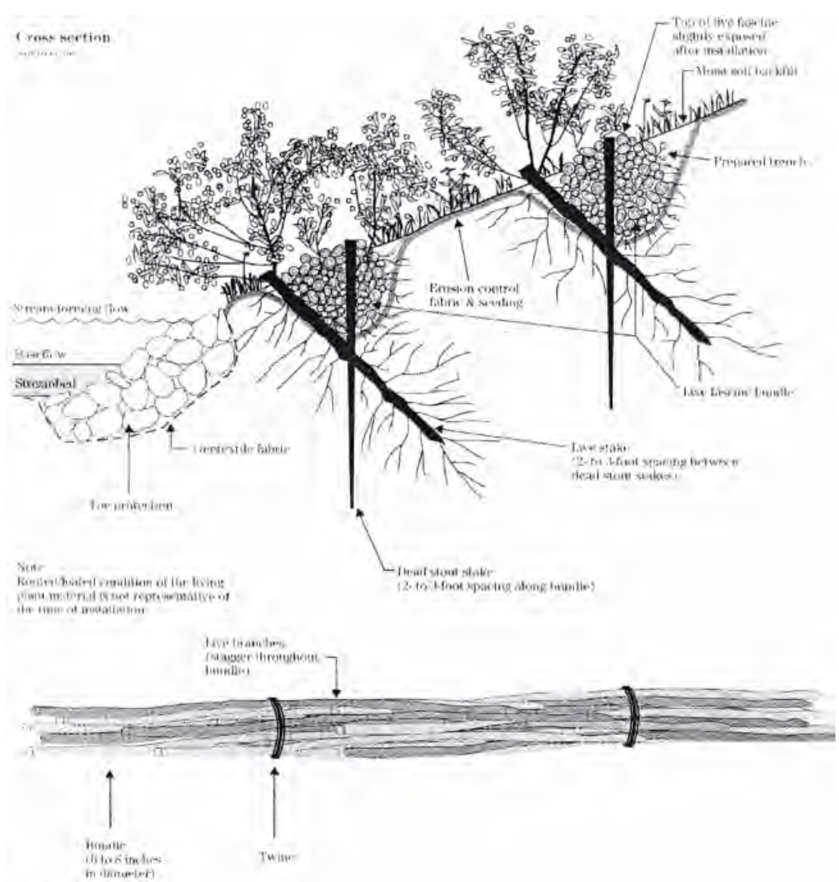


*Figure 1.*

are buried in shallow trenches parallel to the stream. Only the very top layer of branches in the bundle remains partially exposed. The fascines are anchored in the center by dead stout stakes and on the down slope side by dormant live stakes, 2 I/2 to 3 ft. long. The unrooted fascines help to hold the soil on the face of the slope and create mini "terraces" that reduce slope length. Root development soon reinforces the structure. Fascines can also be placed perpendicular to the stream in order to increase channel roughness, or are used in combination with other practices such as brush mattresses (Bentrup and Hoag 1998, Goergia Soil and Water Conservation Commission 1994, King County Dept. of Public Works 1993, USDA-NRCS 1996). When using live stakes, 3/4 to 4/5 of their length should end up below the surface while one or more nodes must remain above ground. Live stakes are also used alone to secure erosion mats or installed with other soil bioengineering and erosion control practices. They may offer a low cost alternative to nursery stock. In the figure, rock is not necessarily the only or best means to protect the toe of the slope.

## Rooting Trials

### Methods and materials

As a follow up to earlier studies, rooting experiments were conducted in a greenhouse mist bench in 2001 to test the ability of snowberry, Pacific ninebark, black twinberry, and salmonberry to root from hardwood cuttings comprised of 1, 2, and 3-yr (±) old wood (Factor C). Secondary objectives were to determine the effect of Wood's Rooting Compound (WRC: 1.03% IBA and 0.66% NAA diluted 5:1 with water) (Factor B) and bottom heat (75°F) (Factor A) on adventitious rooting. Minimum greenhouse temperature was 65°F and the day length was 16 hours. Rooting media consisted of I part peat moss to 4 parts perlite. Experimental design was a randomized complete block with four replications and five, 8 inch cuttings per replication. Analysis of variance (ANOVA) was conducted and Fisher's Protected Least Significant Difference test (FPLSD) was used to separate means at the P=0.05 level. Note that WRC, a mixture of two plant growth regulators (PGRs), is interchangeably referred to as "hormones" in this text.

### Results and discussion

Results for the experiments appear in Table I. For snowberry, as with all species tested, significant differences depended on the variable measured. However, cuttings from 3 year old wood generally rooted and grew as well or better than those from I and 2 year old wood. The highest overall ranking was achieved by 3 year wood without hormones and no bottom heat. There were no significant factor interactions. Bottom heat (75°F) was detrimental to root formation and growth across all ages. WRC significantly improved shoot length and plant vigor in I year old cuttings, but did not have similar effects on 2 and 3 year old cuttings. Rooting was primarily nodal, but substantial amounts formed at the basal ends with minor amounts along the internodes, regardless of age.

For Pacific ninebark, cuttings from 2 and 3 year old stems clearly rooted and grew better than those from I year old shoots. Bottom heat appeared to diminish root development and WRC did not significantly change rooting for either 1 or 2 year old cuttings, regardless of the variable measured. Significant BxC factor interactions for some variables may be attributed in part to the poor rooting of 3 year wood with bottom heat in combination with WRC. The top overall ranking was achieved by 3 year old wood without hormones or bottom heat. Rooting occurred most regularly at the nodes but with fair amounts along the internodes, regardless of age.

In contrast to the other three species under identical conditions, black twinberry appeared to produce a greater abundance of roots. Also, performance was consistently good regardless of age or treatment. Bottom heat decreased basal rooting, but the overall effect was minor, if any. This species roots primarily along the internodes with some basal rooting. As with overall performance, internodal rooting did not diminish with age. Highest overall ranking was for 3 year old cuttings with hormones and without heat, but the results were not significantly higher than those without hormones and no heat.

**Table 1. Effect of bottom heat, rooting compound, and age of wood on rooting ability of common snowberry (SYALL), Pacific ninebark (PHCA11) black twinberry (LOIN5), and salmonberry (RUSP) from hardwood cuttings (in a greenhouse mist bench).**

| Species | Bottom Heat (A) | Rooting Hormone(B) | Age of Wood(C) | Minimum Caliper(mm) | Percent Rooted | No. of Shoots | Shoot Length (cm) | Root Abundance | Root Length (cm) | Plant Vigor | Location of Roots | Overall Ranking |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SYALL | No | No | 1 | 3.6 | 75abcd | 2.6 | 24.1bc | 5.5bc | 17.7 | 6.1bc | N,B,i | 6th |
| | No | No | 2 | 4.0 | 85ab | 2.6 | 33.7ab | 7.1ab | 20.0 | 7.6ab | N,B,i | 2nd |
| **S** | **No** | **No** | **3** | **5.6** | **90ab** | **3.1** | **35.7a** | **7.7a** | **22.1** | **8.3a** | N,b,i | **1st** |
| **N** | No | Yes | 1 | 4.2 | 85ab | 2.6 | 29.8abc | 5.4bc | 17.1 | 6.6abc | N,B,i | 5th |
| **O** | No | Yes | 2 | 4.6 | 100a | 2.6 | 30.1abc | 6.2abc | 17.6 | 7.2ab | N,B,i | 3rd |
| **W** | No | Yes | 3 | 5.9 | 85ab | 2.3 | 30.7abc | 6.0abc | 16.2 | 6.8abc | N,B,i | 4th |
| **B** | Yes | No | 1 | 4.8 | 50d | 2.4 | 21.5c | 4.6c | 13.5 | 5.4c | N,b,i | |
| **E** | Yes | No | 2 | 4.6 | 70bcd | 2.3 | 26.7abc | 4.9c | 16.0 | 5.8bc | N,B,i | |
| **R** | Yes | No | 3 | 5.1 | 53cd | 2.5 | 23.5bc | 4.7c | 17.2 | 6.0bc | N,i | |
| **R** | Yes | Yes | 1 | 3.9 | 80abc | 2.5 | 23.0c | 4.7c | 15.7 | 5.4c | N,b,i | |
| **Y** | Yes | Yes | 2 | 5.1 | 50d | 3.2 | 26.5abc | 5.0c | 18.1 | 6.2bc | N,b,i | |
| | Yes | Yes | 3 | 5.4 | 65bcd | 2.9 | 24.5bc | 5.0c | 15.7 | 6.0bc | N,b,i | |
| Mean | | | | | 74 | 2.6 | 27.5 | 5.6 | 17.2 | 6.4 | | |
| LSD | | | | | 30 | NS | 10.4 | 2.1 | NS | 1.8 | | |
| Significant Factor (ABC) Interactions: | | | | | | | none | none | none | none | none | none |
| PHCA11 | No | No | 1 | 6.0 | 60abc | 1.3cde | 16.4bc | 5.6 | 16.8 | 6.0abc | N,I | 6th |
| | No | No | 2 | 5.2 | 90ab | 3.1ab | 20.6abc | 6.3 | 17.2 | 6.9abc | N,I | 2nd(tie) |
| | **No** | **No** | **3** | **6.9** | **89ab** | **3.9a** | **34.4a** | **7.4** | **19.8** | **8.9a** | N,i | **1st** |
| **N** | No | Yes | 1 | 5.1 | 50cde | 1.5cde | 21.5abc | 5.3 | 16.8 | 5.9abc | N,i | |
| **I** | No | Yes | 2 | 5.8 | 85ab | 2.0cd | 31.1ab | 6.8 | 18.6 | 7.5ab | N,I | 4th |
| **N** | No | Yes | 3 | 5.1 | 90ab | 1.8cd | 28.3ab | 6.0 | 14.3 | 6.4abc | N,I | 2nd(tie) |
| **E** | Yes | No | 1 | 5.6 | 25de | 1.1de | 14.5bc | 3.9 | 7.0 | 4.0cd | N,i | |
| **B** | Yes | No | 2 | 5.2 | 25de | 2.0cd | 18.4abc | 5.8 | 18.6 | 6.5abc | N,I | |
| **A** | Yes | No | 3 | 4.7 | 55dcd | 2.3bc | 25.1ab | 7.1 | 19.0 | 6.8abc | N,I | 5th |
| **R** | Yes | Yes | 1 | 7.3 | 25de | 1.6cde | 17.8abc | 4.9 | 11.0 | 4.8bcd | N,i | |
| **K** | Yes | Yes | 2 | 6.3 | 20e | 2.0cd | 26.6ab | 6.0 | 21.5 | 6.2abc | N,i | |
| | Yes | Yes | 3 | 5.5 | 30cde | 0.8e | 6.5c | 2.8 | 9.1 | 2.7d | N,I | |
| Mean | | | | | 54 | 1.9 | 21.8 | 5.6 | 15.8 | 6.0 | | |
| LSD | | | | | 35 | 1.1 | 16.7 | NS | NS | 3.1 | | |
| Significant Factor (ABC) Interactions: | | | | | | | None | BxC | BxC | none | none | BxC |

**Rooting Hormone** = Experimental Factor B, Wood's Rooting Compound (WRC) at 10:1 dilution. **Minimum caliper** is the minimum caliper which rooted.

**Root Abundance** and **Plant Vigor** based on scale of 10=best, 1=poorest. Means with the same letter are not significantly different at P=.05. **LSD**=Least Significant Difference.

**Root Location** refers to location of roots on the cutting: B(b) =basal. N(n) = nodal. I(i) = internodal. Bold, upper case letters indicate predominant position of roots. Upper case letters (not in bold) indicate 2nd most common root position. Lower case letters indicate minor location of roots. **NS** = not signficant.

**Overall ranking** indicates summary of ability to root based on all parameters (dependent variables) measured. Top 6 of 12 treatments.

**Table 1. Continued.**

| Species | Bottom Heat (A) | Rooting Hormone(B) | Age of Wood(C) | Minimum Caliper(mm) | Percent Rooted | No. of Shoots | Shoot Length (cm) | Root Abundance | Root Length (cm) | Plant Vigor | Location of Roots | Overall Ranking |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LOIN5 | No | No | 1 | 4.3 | 100a | 2.2abc | 16.7cd | 6.8bcd | 21.5bc | 6.9bcd | **I**,B | |
| | No | No | 2 | 4.7 | 95a | 2.0bcde | 23.1abcd | 7.1bcd | 22.6abc | 7.2abcd | **I**,b | 3rd |
| **T** | No | No | 3 | 6.8 | 85ab | 2.4a | 29.0ab | 8.1ab | 27.9abc | 8.0ab | **I**,b | 2nd |
| **W** | No | Yes | 1 | 4.7 | 100a | 2.1abcd | 14.8d | 6.4cd | 24.3abc | 6.4cd | **I**,B | 6th |
| **I** | No | Yes | 2 | 4.7 | 95a | 1.8cde | 23.7abcd | 7.0bcd | 24.1abc | 7.1bcd | **I**,b | 5th |
| **N** | **No** | **Yes** | **3** | **6.6** | **90a** | **2.3ab** | **31.4a** | **8.6a** | **30.5a** | **8.6a** | **I**,b,n | **1st** |
| **B** | Yes | No | 1 | 4.7 | 60cd | 1.8cde | 19.1bcd | 5.9d | 21.1c | 6.3cd | **I**,B | |
| **E** | Yes | No | 2 | 5.3 | 65bcd | 1.6e | 24.6abcd | 6.7cd | 26.1abc | 6.9bcd | **I** | |
| **R** | Yes | No | 3 | 6.5 | 50d | 1.8cde | 17.0cd | 7.0bcd | 29.3ab | 6.1cd | **I** | |
| **R** | Yes | Yes | 1 | 4.6 | 80abc | 1.7de | 14.3d | 6.4cd | 24.4abc | 5.8d | **I**,b,n | |
| **Y** | Yes | Yes | 2 | 5.0 | 80abc | 1.9bcde | 22.0abcd | 6.4cd | 27.3abc | 6.8bcd | **I**,n | |
| | Yes | Yes | 3 | 5.9 | 80abc | 1.8cde | 26.7abc | 7.5abc | 27.9abc | 7.6abc | **I**,b,n | 4th |
| Mean | | | | | 82 | 1.9 | 21.8 | 7.0 | 25.6 | 7.0 | | |
| LSD | | | | | 24 | 0.4 | 11.2 | 1.4 | 8.0 | 1.4 | | |
| Significant Factor (ABC) Interactions: | | | | | | | AxB | none | none | none | none | none |
| RUSP | **No** | **No** | **1** | **6.7** | **75a** | **1.8** | **21.5a** | **6.2a** | **19.6a** | **6.7a** | **I**,**N**,b | **1st** |
| **S** | No | No | 2 | 8.6 | 70a | 1.4 | 13.0ab | 4.4a | 11.9a | 4.9ab | **N**,i,b | 2nd(tie) |
| **A** | No | No | 3 | 12.4 | 40bc | 1.4 | 14.6ab | 6.1a | 19.6a | 4.9ab | **N**,i,b | 4th |
| **L** | No | Yes | 1 | 7.2 | 60ab | 1.2 | 12.0b | 5.3a | 13.4a | 5.5ab | I,N,B | 2nd(tie) |
| **M** | No | Yes | 2 | 10.0 | 10ef | 1.3 | 8.6bc | 4.3a | 10.8ab | 4.1abc | **N**,i,b | |
| **O** | No | Yes | 3 | 11.1 | 25cde | 1.7 | 7.6bc | 3.8ab | 16.6a | 3.3bc | **N**,i | 6th(tie) |
| **N** | Yes | No | 1 | 7.0 | 33cd | 1.3 | 12.6b | 6.3a | 17.5a | 4.9ab | **I**,B,n | 5th |
| **B** | Yes | No | 2 | 8.8 | 15def | 0.9 | 8.2bc | 3.6ab | 11.6a | 4.2abc | **N**,i | |
| **E** | Yes | No | 3 | 15.0 | 15def | 1.8 | 14.9ab | 4.5a | 13.8a | 6.4a | **N** | |
| **R** | Yes | Yes | 1 | 7.3 | 20cdef | 1.1 | 12.1b | 4.5a | 12.6a | 5.1ab | **I**,N | 6th(tie) |
| **R** | Yes | Yes | 2 | <> | 0f | 0.8 | 3.0c | 1.0b | 0b | 1.3c | <> | |
| **Y** | Yes | Yes | 3 | <> | 0f | 0.8 | 2.5c | 1.0b | 0b | 1.3c | <> | |
| Mean | | | | | 30 | 1.3 | 10.9 | 4.2 | 12.3 | 4.4 | | |
| LSD | | | | | 21 | NS | 8.9 | 3.1 | 11.2 | 3.1 | | |
| Significant Factor (ABC) Interactions: | | | | | | | none | none | none | none | none | none |

**Rooting Hormone** = Experimental Factor B, Wood's Rooting Compound (WRC) at 10:1 dilution. **Minimum caliper** is the minimum caliper which rooted.

**Root Abundance** and **Plant Vigor** based on scale of 10=best, 1=poorest. Means with the same letter are not significantly different at P=.05. **LSD**=Least Significant Difference.

**Root Location** refers to location of roots on the cutting: B(b) =basal. N(n) = nodal. I(i) = internodal. Bold, upper case letters indicate predominant position of roots. Upper case letters (not in bold) indicate 2nd most common root position. Lower case letters indicate minor location of roots. **NS** = not significant.

**Overall ranking** indicates summary of ability to root based on all parameters (dependent variables) measured. Top 6 of 12 treatments.

Salmonberry rooted more poorly that the other three species, but achieved the most satisfactory results from cuttings of 1 year old wood, without hormones and without heat (top overall ranking). In general, WRC did not significantly change results regardless of age. Heat in combination with hormones was lethal for 2 and 3 year old wood. There were no significant factor interactions. This species rooted randomly from nodes, internodes, and basal ends, but internodal rooting diminished with cuttings of 2 and 3 year old wood.

In summary, snowberry, Pacific ninebark, and black twinberry generally rooted as well or better from 3 year old compared to I year old cuttings, suggesting that they have good to excellent potential as live stakes, and possibly fascines. This improvement, especially in ninebark, may be the result of larger carbohydrate reserves in older, thicker cuttings. In contrast, salmonberry rooted more poorly from 3 year old cuttings and appears to have less potential for live stakes. However, it still may work in fascines. This species, unlike the other three, may lose juvenile traits as it ages or the bark thickens, becoming less likely to root along the internodes. Finally, for all four species, there appeared to be little if any benefit in the use of Wood's rooting compound (WRC) under the conditions of this experiment and bottom heat (of 75°F) was generally detrimental.

## Streambank Soil Bioengineering Trials

### Site 1: Schneider Creek

The purpose of this demonstration is to evaluate the ability of eight native shrubs to perform as parallel and perpendicular fascines along a streambank. The planting is located along Schneider Creek on the Wynne Farm in Thurston County, WA. Installed March 17, 1999, in a silty clay loam on a gentle slope, trenches were back filled with non-native top soil, fencing was used in 2000, and deer repellent was applied once in 1999. No fertilizer or supplemental water has been applied.

Third year (2001) mean data are shown in Table 2. Despite substantial deer browse and grass competition, sprouting and growth after three growing seasons has been fair to excellent for all species except red elderberry *(Sambucus racemosa)* which failed to establish (I shoot left alive). Perpendicular fascines are outperforming the parallel ones, possibly because of better moisture or soil quality. Pacific ninebark, salmonberry, black twinberry, and redosier dogwood are roughly similar in performance.

As expected, growth and vigor was the highest for both Sitka willows *(Salix sitchensis),* although Douglas spirea produced more stems *per* meter than all other species.

### Site 2: Minnihaha Creek

At a streambank site on the Willamette National Forest (Minnihaha Creek, 2:1 side slopes, elev. 3100 ft.), fascines of nine different shrubs were installed in a droughty, cobbly sand on November 9, 1998. Each fascine was replicated twice, once on a lower tier and once on an upper tier. The lower tier was installed with coir fabric and the upper tier was fertilized at planting (14-14-14 slow release). Trenches were back filled with native soil. A single application of deer repellent was made in 1999. Supplemental water was applied only once each summer. The area was sown to blue wildrye and

**Table 2. Schneider Creek fascines – 2001 results**

| Species | Vigor[1] | Ht.(cm) | Wth.(cm) | Deer Br.[1] | Stems/m |
|---|---|---|---|---|---|
| Sitka willow 'Plumas' | 9.0 | 150 | 150 | 3.0 | 33 |
| Sitka willow (local) | 9.0 | 154 | 147 | 1.5 | 40 |
| Redosier dogwood | 6.0 | 70 | 59 | 5.0 | 10 |
| Douglas spirea | 6.0 | 60 | 49 | 2.5 | 43 |
| Black twinberry[2] | 6.7 | 88 | 50 | 4.0 | 12 |
| Pacific ninebark[2] | 5.7 | 63 | 60 | 2.0 | 11 |
| Salmonberry | 6.5 | 70 | 58 | 3.5 | 16 |
| Red elderberry | 1.0 | 40 | 18 | — | 0.5 |

[1]1=lowest, 10=highest. [2]Mean of 3 plots (fascines).

As expected, growth and vigor was the highest for both Sitka willows mulched. After three growing seasons, mock orange *(Phildelphia lewisii)* and salmonberry are unexpectedly the best performing species (Table 3). Their potential on course soils merits further evaluation. Snowberry is alive but in poor condition, as are single fascines of Indian plum *(Oemlaria cerasiformis)* and Pacific ninebark. Red flowering current *(Ribes sanguineum)* failed to sprout and redosier dogwood, and Scoulers willow *(S. scouleriana)* died by August of the second growing season. The lower tier (rep. 2) is performing slightly better than the upper tier (rep. 1). Low fertility and poor soil moisture holding capacity are probably the major limiting factors at this site, not weed competition.

**Table 3. Minnihaha Creek fascines – 2001 results**

| Species | Vigor[1] | Ht.(cm) | Deer Browse[1] | Stems/m |
|---|---|---|---|---|
| **Mock orange[2]** | **6.3** | **45** | **4.3** | **5.8** |
| Salmonberry | 6.5 | 42 | 4.0 | 3.5 |
| Redosier dogwood | 1.0 | — | — | — |
| Sitka willow | 4.0 | 58 | 3.0 | 2.8 |
| Scouler willow | 1.0 | — | — | — |
| Pacific ninebark[3] | 3.0 | 27 | 2.0 | 1.3 |
| Snowberry | 2.5 | 17 | 5.0 | 8.5 |
| Indian plum | 2.5 | 49 | 2.0 | 0.5 |
| Red flowering currant | 1.0 | — | — | — |

[1]1=lowest, 10=highest. [2]Mean of 3 plots (fascines). [3]One plot.

## Site 3: Frazier Creek

The objective of this study is to evaluate salmonberry, snowberry, redosier dogwood, and Pacific ninebark as both fascines and live stakes. Live stakes of black twinberry are also being evaluated. The plots were installed along Frazier Creek (PMC, Benton Co., OR, elev. 225 ft., 42 inch precip. zone) in a clay soil on February 9 and 12, 2001. Fascines were approximately 6 inches in diameter, 5 feet long, and replicated three times. Live stakes were 2 feet long and replicated twice (5 stakes per plot). Trenches were back filled with a non-native sandy loam. Slow release fertilizer (14-14-14) was used during installation and supplemental water was applied five times. The soil has a high shrink-swell capacity.

First year results are shown in Table 4. Initial performance (June) was initially fair to good for all species except ninebark. Vigor, survival, and stems/meter substantially declined by October. At the end of one growing season, snowberry fascines are performing the best. Because of their construction, they may have had better soil/stem contact and fewer air pockets compared to the other three species. Snowberry may also root more rapidly or is more drought tolerant. Redosier dogwood fascines rank second in performance, followed by salmonberry. Both showed signs of severe drought stress by early October. Only one of three Pacific ninebark fascines produced an acceptable number of shoots (15/meter) in the spring. It may have completely died from drought by fall. While live stakes of redosier dogwood initially survived and grew the best (June), twinberry had the highest survival by October, followed by redosier dogwood, and

**Table 4. Frazier Creek fascines and live stakes – 2001 results**

| Species – fascines | Vigor[1] | | Ht.(cm) | | Wth.(cm) | | Stems/m | |
|---|---|---|---|---|---|---|---|---|
| | Jun | Oct | Jun | Oct | Jun | Oct | Jun | Oct |
| **Snowberry** | **8.0** | **5.3** | **42** | **36** | **31** | **36** | **37** | **34** |
| Redosier dogwood 'Mason' | 5.3 | 1.7 | 31 | 38 | 24 | 38 | 10 | 2 |
| Salmonberry | 4.7 | 2.3 | 33 | 10 | 21 | 10 | 6 | 1 |
| Pacific ninebark | 3.3 | 1.0 | 14 | — | 19 | — | 6 | — |
| **Species – live stakes** | **Vigor[1]** | | **Ht.(cm)** | | **% Surviv** | | **Stems/ls** | |
| Snowberry | 5.7 | 4.0 | 31 | 42 | 50 | 30 | 1.7 | 1.5 |
| Redosier dogwood 'Mason' | 6.8 | 5.0 | 34 | 37 | 100 | 40 | 5.1 | 4.7 |
| Salmonberry | 3.3 | 1.0 | 15 | — | 50 | 0 | 1.0 | — |
| Pacific ninebark | 5.6 | 3.0 | 26 | 24 | 50 | 10 | 3.4 | 3.0 |
| Black twinberry | 6.8 | 4.5 | 31 | 32 | 90 | 78 | 3.1 | 1.9 |

[1]1=lowest, 10=highest. ls=live stake. Wth.=width.

snowberry. Soil "cracks" at the insertion points, compaction, and grass competition may have reduced survival during the dry summer.

### Site 4: Boyce Creek

A fourth installation consisting of salmonberry and sikta willow fascines was made along Boyce Creek in Kitsap Co., WA, in mid-September of 2000 (elev. < 100 ft). The site consists of two planting areas with silt loam soils and 2.5:1 or flatter slopes. Area I has both parallel and perpendicular fascines and is shaded. Area 2 contains over 30 feet of fascines. Leaves were stripped prior to planting. Trenches were back filled with native soil and no fertilizer or supplemental water has been used. At least initially, results suggest that salmonberry (vigor=7.4, ht= 79cm, stems/m= 24) may perform as well or better that sitka willow (vigor= 6, stems/m= 21, ht= 58cm), on moist, shady banks where, unlike willows, it often thrives.

## Summary

I. Under typical greenhouse conditions, it appears unnecessary to use bottom heat (at 75 °F) or a solution of plant growth regulators similar to Wood's rooting compound to root hardwood cuttings of snowberry, Pacific ninebark, black twinberry or salmonberry.

2. Snowberry, black twinberry, and especially Pacific ninebark can root as well or better from cuttings of 3 year old wood versus younger wood. Results suggests they have high potential as live stakes.

3. Salmonberry roots best from cuttings of 1 year old stems and my not do well as live stakes.

4. All four species appear to have fair to good potential as fascines under favorable conditions, but will not root as fast or as predictably as willows.

5. At least initially, it appears some species may have value over willows for soil bioengineering in certain environments (i.e. salmonberry on moist, shady sites or snowberry on droughty soils).

6. Supplemental use of these four species for soil bioengineering provides further options for increasing habitat diversity.

7. Finally, it should be cautioned that field trial results are still preliminary and may change over time. Results can also be substantially affected by ecotype, site conditions, installation technique, stock quality, and handling.

## Future Work

Continued monitoring and additional studies are needed to further define how well these and other native shrubs perform over time under variable soil, moisture, and hydrologic conditions, as well as with other soil bioengineering practices such as brush mattresses and brush layering. Furthermore, anecdotal information suggesting that fall installation of cuttings, live stakes, and fascines may perform as well or better than early spring planting, needs to be validated for select species.

## Acknowledgements

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# The Watershed Revegetation Program: Lessons Learned From Large Scale Native Plant Propagation

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## Introduction

The Watershed Revegation Program (WRP) has been working to restore native plant communities in the Portland area since 1996. The program covers the entire Portland metropolitan area working with public agencies and private landowners to revegetate riparian and upland areas which impact City of Portland Watersheds. During the past five years, the WRP has developed a large scale propagation program for more than 75 native woody and herbaceous species. As a consequence of propagating and installing a large number of bareroot plants and native seed, we have gained knowledge about working with native plants in the context of urban environments. This paper will attempt to share knowledge we've gained in establishing these plants in marginal environments.

## Program History

Since 1996, the WRP has planted over 1.5 million trees and shrubs and managed over 1000 acres on more than 250 sites. The program has four main objectives: to improve water quality, increase biodiversity, enhance wildlife habitat and promote community livability. The WRP has developed a propagation program for more

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than 75 native woody and herbaceous species. This program includes seed collection, processing and mixing; grow-out contracts; plant handling and allocation; and reference site data collection. All woody seed and the majority of herbaceous seed is collected within 50 miles of Portland in the lowlands of the Willamette Valley.

Managing project sites involves site preparation, herbaceous seeding, planting, site maintenance, and monitoring. For most projects, five year agreements are established with each landowner to insure consistency in site monitoring, management prescriptions and implementation. Site preparation or weed management generally includes cutting or mowing followed by herbicide application. Native seed is broadcast using manual spreaders. Seed mixes have been formulated based on commercial availability, site conditions and reference site data. Tree and shrub planting is implemented from late winter to early spring using bareroot material. Plant allocation and design is based on current and projected site conditions as well as historical plant communities. Planting is followed by maintenance and in depth monitoring to assess plant survival and weed conditions.

## Woody Plant Production

We currently have 28 native species of trees and shrubs which are contract-grown by local nurseries. We use primarily bareroot material because it is the least expensive form of woody plant material to grow and install. Most species are sown in the field in the fall with no seed pre-treatment. These include *Acer circinatum, Acer macrophyllum, Amelanchier alnifolia, Mahonia aquifolium, Mahonia nervosa, Cornus nuttallii, Crataegus suksdorfii, Fraxinus latifolia, Holodiscus discolor, Lonicera involucrata, Malus fusca, Oemlaria cerasiformis, Physocarpus capitatus, Ouercus garryaua, Ribes sanguineum, Rosa pisocarpa, Rosa gymnocarpa, Rosa nutkana, Rubus parviflorus, Rubus spectabilis, Sambucus racemosa, Sambucus cerulea,* and *Rhamnus purshiana.* Spring sown species without seed pre-treatment include *Populus trichocarpa ssp. balsamifera, Spiraea douglasii,* and *Alnus rubra.* We cold stratify *Cornus sericea,* and sometimes *Fraxinus latifolia. Symphoricarpos albus* requires a warm-cold stratification before spring sown.

There are a few species we have grown in containers. These are species which are unavailable in bareroot form. *Arbutus meniesii* and *Gaultheria shallon* are grown in Ray Leach Cell plugs. A. *menziesii* requires a cold stratification. Most are ready the first year while others require two growing seasons.

Conifers are grown and purchased from established conifer nurseries. *Pseudotsuga menziesii* and *Thuja plicata* are grown on contract. *P. menesii* is grown as I-I and *T plicata* as a Plug-I. *Abies grandis* is purchased as a 2-0, Ts*uga heterophylla* as a Plug-1 and Willamette Valley *Pints ponderosa* as a I-I or Plug-I. These stock types offer the best quality trees because they have a large root mass, thick caliper, and are easy to handle. Tracking genetics of conifers is easier than most other bareroot plants because the conifer industry consistently keeps detailed records of seed source by seed zone and elevation.

In grow-out contracts, the grower has the majority of the say in maintenance of the crop. Many are undercut, sprayed with fungicide and pre-emergent. Failures have included *Prunus emarginata, S. albus, A. rubra,* and *Philadelphus lewisii.* These have failed due to herbicides, poor seed quality or incomplete stratification. Most are fertilized, watered, and weeded frequently to improve growth. Packing is done in large seedling bags ranging from 100-1000 trees/bag and are stored in a cooler before planting.

### Hybridization threats

A threat to our native plants is hybridization between introduced and native species. We have seen this to occur between the native Black Hawthorn *(Crataegus suksdorfii)* and the English Hawthorn *(C. mouogyna)* and between the native Nootka *Rose (Rosa nutkana)* and Sweet Briar Rose *(Rosa euglanteria).* We have avoided propagating hybrids of Hawthorn by hiring private seed collectors to collect in populations that are void of *C. monogyua.* For Rose, we planted a row of identified *Rosa nutkaua* at our research plot at North Willamette Research Center. This is maintained as a "seed orchard" for *R. nutkana.* The native Black Cottonwood *(Populus basalmifera* var. *trichocarpa)* may be under threat from hybrid Cottonwood plantations.

## Planting and protection

The Portland Metro region has experienced intensive development and urbanization. Establishing native plants in this setting has many challenges. First, the project size is usually small, increasing the edge effect and consequently susceptibility to exotic plant introductions, increased pollution, and other human impacts. Many project sites have compacted soils and are dominated by invasive species- including both plants and nuisance wildlife such as nutria. Establishing pre-settlement vegetation or restoring a "reference" native plant community is not always a feasible goal because of the cost involved. Our program goal is to establish a native tree and shrub canopy layer as well as a dominant native graminoid and forb component. Completion of this goal involves intensive weed management to prepare and maintain the native plant installment at each site.

Planting is implemented using reforestation contractors. Trees are planted in a grid to maximize plant dispersal and to allow for repeated maintenance. Trees are then protected with Vexar tubes and bamboo stakes for support in animal damage prone areas. Tubes have been only marginally successful against Deer and Beaver on favored species, but are good barriers for mice, voles and nutria. Deer seem to prefer T *plicata, M. fusca, and* C. *suksdorfii* and will avoid *P ponderosa, Q. garryana* and *E latifolia.* Mice and voles will target most trees, but seem to avoid *C. suksdorfii, S. racemosa, S. douglasii,* P. *capitatus,* and *S. albus.* Beaver will avoid F *latifolia* as well. A combination of high plant densities and planting unfavorable plant species increases successful establishment of trees and shrubs.

## Tree and shrub establishment

Over the years, we have seen trends in species survival on different site conditions. Species which have great success in dry and compact conditions include *Quercus garryana, Fraxinus latifolia, Pinus ponderosa, P. meniesii, S. albus, Rosa pisocarpa,* R. *purshiana, P. capitatus, S. douglasii,* C. *suksdorfii,* and *B. aquifolium.* Species that must be planted under certain site conditions are *Sambucus racemosa* and *cerulea, Populus trichocarpa, Ants rubra, Cornus sericea,* and *Tsuga heterophylla.* The above species will have excellent performance if they are handled properly and placed in appropriate conditions. Species that have shown preliminary success are *Arbutus menziesii* and *Malus fusca. Acer macrophyllum , Gaultheria shallop, Rubus parviflorus, Rubus spectabilis, Acer circinatum,* and *Philidelphus lewisii* have only shown marginal results. These may need to be grown in a different stock type (in containers) or on more favorable sites.

Plant establishment is dependent on many variables. Soil conditions, weed competition, maintenance treatments, animal damage, and hydrology greatly influence the establishment of each species. Five year old sites have shown to average 59% overall tree survival rate. This has varied from 97% to 26% depending on site conditions. After one growing season in 2000, our average survival rate was 70% for trees and 56% for shrubs. This is mitigated for in our high plant densities (around 2500 trees and shrubs per acre).

## Herbaceous Seed Production

Traditional production of native seed has been primarily grasses. Native grasses have been used successfully for some time in revegetation and erosion control projects. They are comparable to traditional grass seed crops in that they can be sown, managed and harvested with traditional methods. In the past several years, public land managers in the Willamette Valley have recognized the need for re-introduction or enhancement of native forbs, sedges and rushes onto restoration/revegetation sites. This has led to smaller agencies such as the City of Portland to follow leads put forth by the US Forest Service and the Bureau of Land Management to produce native seed themselves or contract out to local seed farmers.

The Watershed Revegetation Program has had seed grow-out contracts with local farmers for the past four years. Through these contracts, the following species were successfully produced between 1998 and 2000: *Alisma triviale (plantago-aquatica), Collomia grandiflora, Eleocharis ovata,* and *Gilia capitata.*

These species have been successfully broadcast seeded onto a variety of site conditions. During 2001, farmers were able to successfully produce seed for an additional 13 species of native herbaceous plants. This seed produced will be used for Fall 2001 and Spring 2002 seeding. The remainder of the 16 species (Table 1) are those which are perennial crops in their first year of production, or those which have failed due to lack of germination, chemical exposure or expense.

**Table 1. Species in Contract Grow-out**

| | |
|---|---|
| *Achillea millefolium* | Western Yarrow |
| *Aquilegia formosa* | Red Columbine |
| *Bromus vulgaris* | Columbia Brome |
| *Carex aperta* | Columbia Sedge |
| *Carex deweyana* | Dewey's Sedge |
| *Carex scoparia* | Pointed-Broom Sedge |
| *Carex tumulicola* | Foothill Sedge |
| *Clarkia amoena* | Clarkia |
| *Collomia grandiflora* | Large-Flowered Collomia |
| *Coreopsis atkinsoniana* | Columbia Tickseed |
| *Danthonia californica* | California Oatgrass |
| *Deschampsia cespitosa* | Tufted Hairgrass |
| *Deschampsia elongata* | Slender Hairgrass |
| *Elymus glaucus* | Blue Wildrye |
| *Eriophyllum lanatum* | Wooly Sunshine |
| *Festuca occidentalis* | Western Fescue |
| *Gilia capitata* | Globe Gilia |
| *Glyceria elata* | Tall Mannagrass |
| *Grindelia integrifolia* | Gumweed |
| *Hypericum formosum* | Western St. John's Wort |
| *Iris tenax* | Oregon Iris |
| *Juncus patens* | Spreading Rush |
| *Koeleria cristata* | Junegrass |
| *Lupinus polyphyllus* | Broad-leaved Lupine |
| *Phacelia nemoralis* | Shade Phacelia |
| *Potentilla gracilis* | Slender Cinquefoil |
| *Ranunculus alismifolius* | Water-Plantain Buttercup |
| *Sidalcea campestris* | Meadow Sidalcea |
| *Sisyrinchium angustifolium* | Blue-Eyed Grass |
| *Tellima grandiflora* | Fringecup |
| *Tolmiea menziesii* | Piggy-back |
| *Wyethia angustifolia* | Narrow-Leaved Wyethia |

## Challenges of native herbaceous seed production

One challenge of native herbaceous seed production is that many native non-graminoids are not easily produced using standard farming methods. This results in a high price that must be paid for the production of native seed. The first challenge is that plot sizes for native species are generally small (.125-10 acres) in contrast with traditional non-native grass crops which range in size from 40 through several thousand acres. In most restoration or habitat enhancement projects, the goal is to re-introduce or enhance the native forb component by seeding a comparatively small amount of a diverse number of species. In addition, a lack of consolidated demand for native seed in the Willamette Valley limits the amount of seed which is produced and stored.

Traditional farming methods such as seed drilling and combine harvest don't work well with many natives because of the desire to retain genetic diversity during production. Unlike cultivars, native (orbs generally produce seed which varies greatly within a species in size, shape and timing for harvest. Many of the pioneering species which compete well in disturbed conditions produce light, fluffy, wind-dispersed seed which are extremely difficult to sow, harvest and clean. In addition to difficulties with traditional farming equipment, chemicals used for maintenance of non-native grass crops are also problematic for native forb and some grass species. Some crops are completely intolerant of chemical applications and must be managed entirely through cultural means.

The size of the crop is also problematic in producing clean seed. Most commercial seed cleaners are set up to clean thousands of pounds of seed at a time. It takes on average a full day to change cleaning equipment between species. For most small crops, this is not a cost-efficient option and crops must be cleaned by hand or by using small, make-shift cleaners.

## Challenges in forb re-introduction

The greatest challenge in seeding project sites is adequate site preparation. As discussed earlier, the majority of Watershed Revegetation Program sites are fragmented riparian areas, comprised of fill soils and dominated by well-established exotic and noxious weeds. On larger restoration or enhancement projects with exhaustive seed banks, the optimal site preparation method would be to remove the top portion of the soil including the seed bank. This is not a viable option on many of our sites. The primary reason is cost and the secondary reason is that most of these fragmented sites don't have the potential to stay "clean" for long.

Rather than reconstruct herbaceous plant communities, it is our goal to create a community of native plants which are able to sustain themselves with competition from non-natives such as reed-canary grass *(Phalaris arundaceae),* exotic thistles *(Cirsium spp),* teasel *(Dipsaucus sylvestris),* creeping clover *(Trifolium repeus),* bird's foot trefoil *(Lotus corniculatus),* etc. Many of the species we work with are those most would classify as native weeds. Most are ubiquitous, have high germination rates or produce millions of seeds per plant. They can be broadcast seeded as opposed to drilled and will germinate even with competition from the seed bank or existing plants.

During the past four years, staff at the Watershed Revegetation Program has taken great care in observing which native herbs may fit this criteria. Fall of 2001 marks the first time we will be able to direct sow a wide variety of native broadleaf and sedge species as well as grasses onto project sites. Although we have collected data on sites where we've sown a variety of native grasses, we have yet to assess the success of broadcast seeding for forbs and sedges.

## Conclusion

Restoration and native plant reforestation are relatively new endeavors in urban, degraded environments. In order for our efforts to be successful, it is important that we share both failures and successes in plant propagation and establishment. We hope that this information shared will benefit restoration practitioners throughout the Willamette Valley.

## Acknowledgements

Our sincere thanks to Brooks Tree Farm, Willamette Seedling Nursery, Seven Oaks Native Nursery, Kenagy Family Farms, Mid-Valley Natives, and Pacific NW Natives for being open to experiment with new species and adapt to challenges inherent in growing natives. Also thanks to Silver Mountain Nursery, Beaver Pond Natives, Triangle Farms, Portland Parks Horticultural Services, and all other growers and contractors that we have worked with. We are also indebted to our coworkers and other supporting agencies that have helped us through the revegetation process.

# Geomorphic Aspects of Riparian Area Revegetation and Environmentally Sensitive Streambank Stabilization

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## Abstract

Riparian vegetation and channel morphology are closely coupled in small- to moderate-sized streams. Knowledge of plant/channel interactions should therefore help guide revegetation efforts along streams, even where channels and catchments have been substantially altered by land use activities. Bank stabilization is an important impetus for riparian area replanting and the overall level of energy associated with stream type will influence these efforts, as will the innate strength of bank materials. Other important factors affecting planting include the variable distribution of energy within the channel and the different planting conditions associated with bank morphology. It is especially important to create lower angle, stable planting surfaces along deeply entrenched streams if meaningful bank stabilization is to be achieved. And while soil bioengineering has wide application to man-modified channels, there are many situations where bioengineering systems are ineffective at providing streambank stabilization.

**Keywords**

Geomorphology, stream morphology, erosion, bank stability, soil bioengineering

## Introduction

Because native woody vegetation provides so many environmental services in riverine environments, restoring riparian vegetation is a central feature of efforts to rehabilitate degraded watercourses. This is particularly true for streams within

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intensively managed landscapes, such as urban and agricultural areas. Native plant communities in these areas have often been conspicuously altered if not destroyed altogether.

A large share of riparian revegetation activity occurs along urban and farmland streams which no longer possess a 'natural' stream corridor topography, including a functional (commonly inundated) floodplain. These streams have been artificially straightened and deepened, or have undergone incision due to land use changes, and commonly possess quite simple cross sections with very steep channel banks. Such channels are often closely confined by urban infrastructure or agricultural fields.

Scientific advances over the last several decades have underscored the tight coupling between riparian vegetation and the physical processes shaping stream channels and their floodplains. Moreover, it is now clear that natural disturbances, especially large but infrequent floods, are important to the long-term healthy functioning of rivers and streams. However, the practical relevance of natural disturbances to city and farmland streams is equivocal at best. Not only have the catchments of such streams been substantially altered, so that "natural" hydrologic conditions no longer occur, but the channel alterations which accompany major floods are considered calamitous because of the damage wrought on human infrastructure and properties. And while lateral channel migration is vital to the development of healthy habitat in landscapes mainly free of cultural constraints, it is doubtful that a migrating channel can create useful habitat when the stream is deeply entrenched, tightly constrained by adjacent development, and bordered by little or no woody vegetation. These are all common conditions in managed landscapes. Even in those rare instances where a wide stream buffer has been reserved, additional fine sediment input from accelerated bank erosion may be unacceptable in streams where fine sediment loading is a major factor limiting biological integrity. Moreover, these streams are typically far more prone to accelerated erosion than they were formally because of degraded riparian conditions and the higher stream energy (from higher and more frequent peak flows) associated with watershed imperviousness.

While channels usually need to remain essentially stationary in developed areas, revegetation work here must still be guided by a geomorphic perspective. Many riparian revegetation projects have been compromised by inadequate attention to geomorphic circumstances, such as an area's susceptibility to bank erosion. In keeping with the practical emphasis of this conference, the following discussion will focus on observations pertinent to "hands on" riparian restoration, especially in the degraded situations where such efforts are most urgently needed. Riparian revegetation issues associated with wilder stream systems, such as cottonwood gallery forest regeneration, are not covered here. The role of vegetation in bank stability is emphasized because riparian replanting is often undertaken largely to encourage bank stability on streams that can no longer be allowed to wander.

## Riparian Vegetation Influences on Channel Form and Stability

Vegetation-lined channels are, in general, far more stable than unlined channels in virtually all situations and meandering channels migrate much more slowly (but migrate nonetheless) when banks are well defended by vegetation. In terms of overall channel geometry, the stabilizing influence of streamside vegetation tends to make active channels narrower and deeper than they would be otherwise. This effect is greatest for small to moderate sized (lower order) streams; vegetation appears to have far less influence on larger channels. The effect of vegetation on bank stability is also reduced when banks are too steep to support vegetation and when bank height is substantially greater than the rooting depth of the vegetation (as in many large rivers or entrenched channels of any size).

Scour and mass failure are the two principal mechanisms of bank failure on alluvial streams. Vegetation imparts resistance to these processes in two key ways. First, by directly reinforcing the bank with dense, fine root networks, closely-spaced woody plants or a dense herbaceous layer bind together and increase the resistance of bank materials to particle entrainment by the force of flowing water. Deeply-rooted woody plants can also help to prevent mass failures (slumps and slides) if the roots extend across potential failure planes. The second major *effect* may be most noticeable during high flows, when channel velocities and the potential for bank scour are greatest. In this case, the submerged stems and exposed root structures of plants on the bank create high bank roughness which fends off and dissipates flow velocity and therefore reduces the force of the flow (or boundary shear stress) along the channel margin. Generally less critical as stabilizing influences are the surface resistance to rainfall erosion that a cover of vegetation (especially groundcover vegetation) imparts and the buttressing effect that large trees growing low on the bank can provide. This last effect can be problematic because while lower bank trees can prevent mass failure, they can also form hard points which can actually promote bank erosion.

Of the two main failure mechanisms, mass wasting is generally the most important process on lower gradient streams traversing fine-grained alluvium. Such streams are common in many lowland urban and farmland areas. However, basal scour along the toe of the bank can also be of vital importance because this often triggers mass failure. Scour occurs primarily along the toe of the outer bank at channel bends, especially downstream of the bend apex. Basal scour here reflects the formation of a strong secondary current associated with the centrifugal acceleration of flow caused by bend curvature. Basal scour is the most difficult process to control with vegetation because it commonly occurs below the level where plants can become established and grow (the summer water level) or because propagules or young plants are removed by scour before they can become established.

It is worth noting that woody vegetation does not necessarily provide greater bank stability than a dense sod of sedges and grasses. In fact the reverse may commonly be true, especially where banks remain low (or have been deliberately regraded to a lower angle). The root mat of herbaceous plants can tightly bind such banks, whereas forest vegetation may inhibit the growth of graminoids, resulting in an overall reduction in root reinforcement. Large trees growing on low banks may also be shallow rooted due to a high water table. These trees tend to topple into the channel because of undercutting and windthrow. Once this large woody debris enters the channel (particularly in small streams), it commonly diverts flow against the banks, causing them to erode.

Despite these conditions, riparian planting usually focuses on trees and shrubs because of the other environmental services these plants provide, such as improvements to water quality (e.g. shade for temperature control) and habitat improvement (food chain support, cover, etc.). It is therefore important to know where and how to install woody riparian vegetation in order to reap these benefits while simultaneously providing the level of bank stability required in managed landscapes.

## Vegetative Stabilization and Stream Type

One of the more useful ways to classify channels is by stream power (or energy) and by the nature of the bed and bank materials in which the channel is formed. As used here, stream power is a measure of a stream's overall ability to erode and transport particles and is a function of the channel's shape, slope and discharge. Stream power reflects a stream's ability to do geomorphic work and increases with channel slope and discharge. This needs to be considered in conjunction with the erodibility of channel bed and bank materials, which can vary greatly.

Steep, deeply entrenched creeks (where most flows are confined to the channel) represent high stream power sites wherever they are subject to very high streamflows, even if this is only intermittent. Small but relatively steep creeks which have become deeply incised within erodible silt-rich alluvium are common in managed landscapes. These streams can erode very rapidly during significant flow events. Riparian planting will neither stabilize these banks nor insure the development of a healthy woody riparian fringe here because progressive channel widening is likely to remove this vegetation before it can mature. Structural countermeasures must be used in such cases to resist channel widening and create surfaces capable of physically supporting a healthy stand of vegetation.

In contrast, even a much larger stream with a very low gradient, especially a stream which retains a broad geomorphic floodplain which can dissipate stream energy during high flows, represents a low stream power situation because flow velocities are never very great. Such low energy streams also often traverse floodplains of highly cohesive (clay-rich) alluvium which is naturally resistant to erosion. Even outer bend banks may be relatively resistant to erosion in this situation, especially when bank strength is enhanced by a dense sod on the floodplain surface. While there may be no physical obstacles to planting trees and shrubs in these areas (which usually have to be hydrophytes adapted to high water tables), many of these may be wet meadow streams which should not necessarily be bordered by a continuous thicket of woody vegetation.

## Riparian Planting and Channel Morphology

The margins of natural alluvial channels with intact floodplains are far from uniform. Both the meandering channel and the complex microrelief of the floodplain and adjacent terrace or colluvial slopes provide a tremendous variety of microsites for plant growth. Probably the most important site variable is soil moisture. An essentially intact riparian corridor in a similar biophysical setting as the restoration reach can provide a template (or reference site) for restoration. The observed association of species with different root zone conditions should be reflected in the planting strategy for even highly altered, simplified watercourses. For example, a plant tolerant of persistent inundation should be planted in the lower bank zone regardless of whether the stream is natural or channelized.

At a very basic but frequently neglected level, the overall stability of the channel should always be assessed prior to planting. Widespread bank failure accompanies channel deepening and/or widening in degrading streams, and channel aggradation can force the current to the channel margin, likewise causing bank erosion. Trees and shrubs planted at the top of steep, bare banks which are actively eroding cannot prevent further bank failure. In fact, the effectiveness of vegetation planted at the top of the bank along such streams declines as bank height increases because less of the root mat covers the bank face. Moreover, droughty root zone conditions may occur along the top and waterside edge of tall, steep banks. This can greatly reduce the survival of tree and shrub seedlings or live cuttings because root growth cannot stay apace of the seasonal decline in the water table. Even supplemental watering may not insure the survival of plantings in this situation.

Where slope angle allows it, it is often useful to plant woody vegetation as low along the bank as it will grow since bank erosion is frequently precipitated by flood-generated scour along the lower bank and the most cover for aquatic organisms is provided by plants which closely interact with the wetted channel. Once established, woody plants in the lower bank zone can provide good resistance to erosion in those portions of the river planform where the highest velocity current the *thalweg,* or line of greatest channel depth) does not hug the streambank. Although bank toe plantings would typically be useless along the outside of a channel bend, live cuttings of brushy streamside plants such as willows may be installed even along the toe of steep banks in crossover reaches and along inside bends with some assurance that these plants will survive.

At the same time, it is important to recognize that trees and shrubs situated low in the channel cross section may tend to capture floating debris, causing debris jams which promote bank erosion and/or reduce flow conveyance in narrow channels. Vegetation choked channels can cause unacceptable levels of backwater flooding along constrained urban streams. Non-pliant woody plants (especially trees) should be planted higher up on the bank in these situations and shrubs growing lower in the cross section may require periodic pruning.

As already pointed out, there is little point to installing woody plantings or pole cuttings along the face of bare, oversteepened banks which are naturally subject to stream scour. By creating eddies in their vicinity, large plants or poles in these locations are more likely to exacerbate erosion than solve it. For this same reason, trees growing along the lower part of the bank can act as hard points, causing bank scour because of the local acceleration of flow in the eddy formed by the tree trunk. Prominent clumps of woody vegetation can also act in this way. To avoid scour in intervening areas, trees should be spaced relatively close together, so that the turbulent zone created by one tree intersects with the next tree downstream. In order to minimize these effects, trees should generally be planted higher up on the bank, especially in confined systems. On the other hand, the undercut root systems of streambank trees such as alders can provide wonderful fish cover in areas of moderate scour. Trees planted to ultimately achieve this effect should be associated with dense thickets of shrubby vegetation or a good sod cover so that the bank is fully protected.

Woody plants should not ordinarily be deliberately planted within the active channel of streams. (The *active channel* is that portion of stream where flow occurs frequently enough to normally prevent the persistence of woody vegetation.) Gravel bars and sandy shoals within this zone are typically mobilized by relatively common floods, which are likely to erase any planting effort. Woody vegetation which has become established on a bar (e.g. after a number of dry years) can cause bank erosion when ordinary high flows return. On the other hand, what superficially appears to be the active channel may instead be an artifact of deliberate or induced channel widening. In over-wide channels, planting woody vegetation on bars or shoals may be an appropriate strategy for narrowing the low-flow channel and improving instream habitat conditions. Soil bioengineering methods designed to induce sedimentation (e.g. live brush sills) may be helpful in these areas. Planting within the apparently active channel needs to be preceded by a careful assessment of stream conditions.

A "relaxed" approach to long-term stabilization can be taken with some alluvial streams. In this case, woody plants are installed some distance from an actively migrating meander bend with the idea that the channel will eventually encounter a resistant phalanx of mature plants with well-established root systems. This technique is obviously only reasonable where a floodplain has been reserved for channel migration.

## The Importance of Stable Planting Surfaces

Vertical or extremely steep banks cannot provide a platform for vegetation and are inherently unstable because of the absence of this vegetation and their natural propensity to mass failure. Such banks must be converted into stable, low angle surfaces in order to successfully restore a thriving plant community. A rule of thumb is that slopes should generally be cut back to an angle of no greater than 2H:IV and ideally 3H:IV or lower. Even unreinforced banks with an angle of 3H:IV or lower are typically immune to geotechnical failure. Reducing the bank slope also enlarges the flood conveyance cross section, thereby reducing flow depth. This, in turn, dissipates flow energy and reduces shear stress on the channel bed and banks. Lower bank angle also increases the opportunity for water to infiltrate into the bank (thereby increasing soil moisture content) and for fine sediment to settle on the bank. Both effects can provide more favorable circumstances for riparian vegetation.

A lower slope angle also allows surface soils to be amended (with composted organic material, for example) to better support a vigorous plant community. The thriving riparian vegetation associated with a richer soil is far more capable of stabilizing the bank and providing beneficial habitat than a few struggling trees and shrubs growing on a bank composed of dense, nutrient-deficient subsoil. Reconstituting the soil over the entire regraded slope surface will prevent otherwise hostile soils outside the planting hole from eventually stifling plant growth.

In lower energy situations, such reprofiled streambanks do not have to be bioengineered. Typically all that is required is a temporary covering of biodegradable erosion control matting which will serve to protect the surface until groundcover vegetation is established. Woody vegetation can be planted on the regraded surface but will also commonly volunteer here. Woven coconut fiber or jute matting, fastened with wooden stakes, are ideal products for temporary erosion protection since they conform to the soil surface and eventually rot away. The mesh openings of these fabrics also tend to capture waterborne plant propagules and a covering of fine sediment. Banks covered with erosion control fabric are most conveniently and inexpensively planted to woody vegetation by inserting live cuttings ("live stakes") through the mesh openings.

Herbaceous groundcover is important on all reconstructed bank slopes, as much for protection against rainfall erosion as for defense against fluvial erosion. Although re-seeding with native or sterile grasses is increasingly being mandated by "natives only" policies, traditional, non-native erosion control grasses may have certain benefits, including more rapid growth, better root binding qualities, much lower cost, and easy availability. Native grasses are typically replaced by alien species within a few years anyway in weedy urban or agricultural landscapes. In terms of promoting native woody vegetation, a case might be made for using an aggressive, non-native but low-profile groundcover plant mix. This can both insure erosion control and help to exclude taller, even more aggressive weeds such as reed canarygrass and tall fescue, which can overwhelm the seedlings of native trees and shrubs.

## Soil Bioengineering

More elaborate structural measures are required for bank stabilization where closely encroaching infrastructure hinders regrading the bank slope and/or in areas where basal scour is significant. It may also be disadvantageous to further enlarge (by regrading) channels which are already too wide and more involved structural measures may be required here as well. Soil bioengineering can be a successful approach to both riparian vegetation restoration and streambank stabilization in many of these cases.

*Soil bioengineering* refers to the use of plant materials (usually live cuttings) to provide immediate mechanical reinforcement and slope protection until the plants themselves grow into a dense thicket capable of providing permanent slope protection. In many applications, inert materials such as rocks, logs or geotextiles are used in conjunction with plant materials. (Although this is sometimes distinguished as *biotechnical stabilization,* all of these allied methods are here considered soil bioengineering.) By re-establishing vigorous vegetative growth along streambanks, these methods not only protect banks from erosion but provide both habitat and aesthetic improvements, benefits conspicuously absent from conventional engineering treatments such as rock riprap or concrete walls. Common examples of soil bioengineering bank stabilization methods include vegetative geogrids, brush mattresses, live cribwalls, and coconut fiber roll applications.

As soil bioengineering techniques have become more popular for obvious environmental reasons, so too have a number of misconceptions concerning the details of their construction. For example, it appears to be widely assumed that soil bioengineering can virtually eliminate the need for hard bank structures. This is far from the case. Damaged banks in low energy settings may be stabilized with little or no reliance on hard structures, but outer bend banks in moderate to high energy environments — areas where erosion control is most often needed — generally require a permanently hardened bank toe. This bank toe revetment is usually composed of large rock fragments, with the vegetative soil bioengineering components applied above this point. For the sake of extra security (and often because of low confidence in biotechnical techniques), the rock toe may be carried up to the ordinary high water level. This is far too much rock in most cases: it should generally be sufficient to carry the rock toe no higher than the baseflow level, or observed lower limit of woody vegetation growth. Although more rock than necessary is often installed, its is important for all stakeholders to realize that rock will nonetheless be important in any soil bioengineering scheme capable of defending a scour-prone bank.

As soil bioengineering techniques have become more popular for obvious environmental reasons, so too have a number of misconceptions concerning the details of their construction. For example, it appears to be widely assumed that soil bioengineering can virtually eliminate the need for hard bank structures. This is far from the case. Damaged banks in low energy settings may be stabilized with little or no reliance on hard structures, but outer bend banks in moderate to high energy environments — areas where erosion control is most often needed — generally require a permanently hardened bank toe. This bank toe revetment is usually composed of large rock fragments which, for the sake of security, may be carried up to the ordinary high water level (with soil bioengineering methods applied above this point). In most cases, it should be sufficient to carry the rock toe no higher than the baseflow level, or observed lower limit of woody vegetation growth. Although more rock than necessary is often installed, it is an important element in virtually all soil bioengineering schemes capable of defending scour-prone banks.

Another issue is that even bioengineering prescriptions do not preclude the need to create stable planting surfaces for long-term stability. Hugo Schiechtl, the dean of soil bioengineering methods, recommends that slopes to be treated by soil bioengineering should normally not exceed 3H:IV and only in exceptional cases should be allowed to approach 2H:1V or 1.5H:IV. Despite this, soil bioengineering treatments are frequently applied to much steeper slopes, even when site conditions are such that they don't need to be. Although minimizing bank excavation can save cost in the short run, the long-term stability of the site may be in jeopardy.

An additional important issue concerns some significant limitations to the use of soil bioengineering methods in different landscape settings. Many practitioners appear to be unaware of these restrictions. Important examples are described below:

### Shady sites

Shrubs and small trees of the genus *Salix* (willows) are far and away the main woody plants upon which most bioengineering applications rely. There are many reasons why willows are especially valuable for soil bioengineering applications. They are tolerant of inundation and wet soils; they root easily from cuttings; they are naturally invasive and self-repairing after damage; they grow rapidly to produce a bushy topgrowth which can dampen flow velocity (especially *if* periodically pruned); and they develop dense fibrous root networks capable of *effective* bank reinforcement. On the other hand, as early seral species, willows are typically intolerant of shade and grow vigorously only in open locations.

Shade intolerance represents a significant limitation on the use of bioengineering techniques since it is common to find severe bank erosion problems on small streams under a relatively dense forest cover. These streams cannot be successfully treated with bioengineering methods unless the tree canopy is first removed. Soil bioengineering applications are also precluded in areas which are shady because of adjacent buildings or topography.

### Small, culturally constrained streams

Dense bankside vegetation can have an importance influence on channel flow capacity in smaller streams, especially if they are deeply entrenched. This describes many lower order channels traversing cities or farms. Although soil bioengineering along such a stream may require bank excavation, the stream remains a narrow one. The development of a dense growth of willow along these channels can increase flow resistance and exacerbate local flooding. It can also force flow against an unprotected bank, causing scour. Heightened flood risk, in particular, can be an important practical limitation when the floodprone properties include streets and buildings.

Because of conveyance concerns, Schiechtl recommends that brushy willow species should, in general, not be planted along streams where the minimum streambed width is less than about 15 feet. This obviously includes a lot of urban streams and soil bioengineering is frequently attempted along such channels. On the other hand, there are instances where soil bioengineering methods can be successfully applied to small streams. Examples include relatively low power streams with low banks, creeks which retain a geomorphic floodplain, streams where the bank opposite the treated one is already hardened, or streams where additional flood rise is not a problem.

### Entrenched and actively incising channels

Soil bioengineering methods cannot be used to stabilize steep incised channels which have yet to encounter resistant streambed materials. This is because plants capable of checking erosion do not grow in the streambed and plants cannot defend against scour along the bank toe. Only grade control structures such as stone or log weirs or sills ("check dams") can prevent channel incision. At the same time, the banks of streams with grade control must be stabilized by reprofiling to a lower angle and/or by applying hard bank revetments. This is required because a channel that is prevented from adjusting vertically will attempt to do so laterally. In essence, the entire channel cross section must be made stable in incised channel rehabilitation. So-called "hard" streambank revetments (e.g. rock walls or riprap) will generally be required in the immediate vicinity of the grade control structures (on both banks), even if other re-contoured banks can be successfully stabilized by soil bioengineering or by simply replanting them.

## Conclusions

The following general recommendations are provided with respect to bank planting along streams in intensively managed landscapes:

- Geomorphic processes and conditions should be factored into any planting strategy.
- Stream type with respect to overall stream power, channel morphology, and the texture of bed and bank materials is an important consideration in replanting.
- Plantings installed along the top of steep, actively eroding cutbanks are unlikely to thrive and will probably be removed by erosion before maturity.
- Large trees should often be planted higher on the bank along smaller streams which lack a functional floodplain in order to minimize the risk of future bank erosion and flow conveyance issues associated with the trapping of flood-borne debris.
- Trees and shrubs should generally not be installed within the active channel (below the ordinary high water line) unless the channel is overly wide.
- In over-wide channels with steep banks, shrubby plants such as willow may be installed low on the bank, with some confidence for success, as long as it is not in areas where the main current directly impinges on the channel margin.
- A hardened bank toe is generally required to stabilize and revegetate areas where the thalweg or high velocity current converges on the bank, such as an outer bend bank or where an inchannel obstacle diverts flow against a bank.
- Riparian replanting success and stabilization effectiveness are maximized on banks which have been regraded to a lower angle and which have had their surface "soil" reconstituted.
- Soil bioengineering techniques cannot generally be used in shady reaches and should be used cautiously (if at all) along narrow, culturally constrained streams which are already susceptible to backwater flooding.
- Incising channels cannot be stabilized by simple planting or with soil bioengineering techniques.

"Hard" bank structures are likely to be required in areas where channel migration is unacceptable but soil bioengineering techniques cannot be employed. These techniques can nonetheless be environmentally sensitive bank prescriptions which maximize the opportunities for riparian vegetation growth and persistence. Examples include log cribwalls, natural stone toe treatments, and plantable retaining walls. Conventional full bank riprap blankets and gabion walls are only rarely justified.

# Biographies

## CLAY ANTIEAU

### Biology, Ecology, and Management of Invasive Plants

Clay Antieau M.S., Ph.C. is a horticulturist, botanist, and environmental scientist who enthusiastically combines these disciplines to offer unique abilities and perspectives in horticultural and environmental education and environmental science. Clay currently works for the City of Seattle, implementing the Habitat Conservation Plan for the City's municipal drinking water supply, the Cedar River Watershed. Clay is a recognized local authority and educator in Northwest native plants and has taught or lectured on this, wetland science, restoration science, and related subjects at the University of Washington and numerous technical and community colleges around Washington.

## CAROL BASKIN

### Some Procedures for Dormancy Break and Germination of Difficult Seeds

Carol Baskin is a professor in the school of biological sciences at the University of Kentucky.

Her research interests include plant ecology, ecological life cycles of herbaceous angiosperms, seed germination ecology, biogeography, and evolution. She has authored over 300 publications. Recently she was awarded Botanical Society of America Merit Award, 2001 and The New York Botanical Garden Henry Allan Gleason Award for an outstanding recent publication in the field of plant taxonomy, plant ecology, or plant geography—this award was for the 1998 book she co-authored with husband Jim: *Seeds: Ecology, biogeography, and evolution of dormancy and germination.*

## ANN CHANDLER

### Growing and Managing Site Specific Plants in the Nursery

Ann obtained her BS in Ornamental Horticulture and Nursery Management from Washington State University. She started Cornflower Farms in 1981. During these 20 years, she was afforded the opportunity to gain considerable experience in growing and management of natives for wildland restoration and site revegetation. She has a strong affinity to field-oriented practical problem solving

## BERNADETTE COONEY

### Opportunities to Improve Ectomycorrhizal Colonization

Bernadette became a Peace Corps Volunteer after earning a B.S. in Environmental Science. Following her Peace Corps tour in Honduras as an Agro-forestry Extensionist, she became the Director of Reforestation for the Bay Islands Development Association. Since returning to the U.S. she has worked for Weyerhaeuser within the Nurseries and Orchards Unit, as well as, in Research and Development. After completing her M.S. in Forestry she became the Manager of the Gene Conversion Program for Monsanto. Most recently, she was the Director of Plant Production for Bitterroot Restoration. Bernadette is presently a free agent due to company downsizing. She hopes to continue working in the field of ecological restoration as she finds it very appealing due to the scope and diversity of the work.

## DALE DARRIS

### Native Shrubs as a Supplement to the Use of Willows as Live Stakes and Fascines in Western Oregon and Western Washington

Dale Darris is a Conservation Agronomist for the USDA Natural Resources Conservation Service at its Plant Materials Center in Corvallis, OR. He grew up in Michigan and obtained a Bachelor of Science in Plant (Crop) and Soil Science from Michigan State University. He also did graduate work in Forest *Science* at Oregon State University. For over two decades he has increased plants and studied grass seed production, woody plant propagation, and revegetation techniques while holding research and management positions at similar facilities in North Dakota, Maryland, and Oregon. Current projects include seed germination, seed and vegetative plant increase, and establishment technology for a variety of shrubs, grasses, and legumes indigenous to Pacific Northwest ecosystems west of the Cascades.

## ROBERTA (BIRDIE) DAVENPORT

### Techniques Used to Restore Puget Prairie Communities and Rare Plant Habitats

A Northwest native, Birdie has lived in Olympia for 25 years. After college graduation, she worked for the Forest Service in wilderness, trails, restoration and forest ecology for seven years. She completed a Masters of Environmental Studies degree at the Evergreen State College in the early 90's. For the last 9 years she has been with the Washington State Natural Areas Program. Her focus has been on restoration, especially Puget Prairies, monitoring, and educational programs.

## KAS DUMROESE

### Propagation Protocols on the Native Plant Network

Kas received his Bachelor of Science in Forest Management from Michigan Technological University in 1984, and his Master of Science and PhD in Forest Resources from the University of Idaho in 1986 and 1996. For the past 17 years Kas worked at the University of Idaho Forest Research Nursery, first as a graduate student and assistant manager and finally as a research scientist. For the past decade his emphasis has been on applied nursery research and technology transfer. In 1999, as part of cooperative program with the USDA Forest Service State and Private Forestry, Kas initiated the *Native Plants Journal* and continues to serve as editor-in-chief. This summer he accepted a position as plant physiologist with the USDA Forest Service Southern Research Station to continue his work with nursery research, technology transfer, and the journal.

## STEVE FEIGNER

### Forb seed production at J. H. Stone nursery

Steven Feigner has been the culturist at J. Herbert Stone nursery since 1989. In 1975, he received a B.A. in biology from Southern Oregon University. He spent two years at Oregon State University, working on a M.S. in forest pathology. Steve has more than 20 years of experience in forest nursery work at the J. Herbert Stone nursery. He has participated in many of the innovations that have transformed J. H. Stone nursery into a facility that produces native grass seed, native forb seed, container plants and many non-traditional species.

## DIANE HAASE

### conference organizer and proceedings editor

Diane Haase has been the Associate Director of the Nursery Technology Cooperative at Oregon State University since 1991. She has forestry degrees from Humboldt State University and Oregon State University. Her position with the NTC involves development and implementation of projects in the areas of field reforestation, nursery practices, pest management, and plant physiology. In addition to this conference, she has coordinated successful conferences on seedling nutrition and advances in reforestation practices.

## TOM KAYE

### Keynote presentation: *Common Ground and Controversy in Plant Restoration*

Tom Kaye is Executive Director of the Institute for Applied Ecology, a non-profit organization dedicated to natural resource conservation, research, and education. He graduated with a BS from The Evergreen State College (1980) and received MSc (1989) and PhD (2001) degrees from Oregon State University. After working for Olympic National Park (1984-1987), he joined the Oregon Department of Agriculture's Plant Conservation Biology Program (1988-2000) where he conducted research and contributed to policy for management of threatened and endangered plant species. He has served on the IUCN Species Survival Commission, Re-introduction Specialist Group and is a member of the Native Plant Society of Oregon.

Tom specializes in native and endangered plant propagation and restoration, the population dynamics of rare plants, population viability analysis, development of habitat management and restoration techniques, and monitoring. In addition, his interests include plant-pollinator interactions and plant systematics.

## ANGIE KIMPO

### Challenges in Large Scale Native Plant Production and Revegetation

Angela Kimpo is a Botanic Specialist for the Watershed Revegetation Program at the City of Portland. She received a BS in Forestry from the University of Washington. From 1997 to 1999, Angela worked at the King Conservation District coordinating native wetland emergent propagation for the Wetland Plant Cooperative. Since 1999, Angela has been the Coordinator for herbaceous seed grow-out efforts for the Bureau of Environmental Services.

## KELI KUYKENDALL (paper not submitted)

### The Native Seed Network: A Resource for Restoration

Keli Kuykendall is the Director of the Native Seed Network, an effort to bring together growers, restorationists, and researchers and facilitate native seed marketing and exchange. She is a natural resource scientist with expertise in Pacific Northwest ecosystems, terrestrial and wetland, east and west of the Cascade Range. She has worked for over 15 years on conservation of native plants in Oregon and Washington. Keli has a Master"s degree in Botany and Plant Pathology from Oregon State University, and is a founding member of the Carex Working Group, an affiliation of scientists who have spent ten years documenting the distribution and taxonomy of sedges in Oregon. She recently assisted Marion County, Oregon with large-scale native plant restoration projects. Keli has published numerous articles on native plant propagation and restoration, and teaches courses and professional workshops on the use of native plants.

## TOM LANDIS

### The Target Seedling Concept: The First Step in Growing or Ordering Native Plants

Tom has forestry degrees from Humboldt State and Colorado State Universities. For the past 21 years, Tom has provided technical assistance and technology transfer services to nurseries in the U.S. as the National Nursery Specialist. Some of his technology transfer services include *Forest Nursery Notes* which is a semiannual newsletter and targeted literature service, and technical books including the *Container Tree Nursery Manual* and the *Forest Nursery Manual.*

## JOYCE LAPP

### Partnerships in Restoration and Education in Glacier National Park

Joyce is a native Montanan and graduated from Montana State University with degrees in Horticulture and Soils Science. She has worked in Glacier National Park since 1987, first as Nursery Manager and for the last several years as Restoration Biologist and Horticulturist.

## BILL MCDORMAN

### Techniques and Considerations for Native Plant Seed Collection

Bill McDorman is president of Seeds Trust, High Altitude Gardens, founded in 1984. It remains one of the world's only seed companies specializing in finding, testing and producing seeds for high elevations including 100 varieties of wildflowers. Bill has been asking and answering questions about seeds and seed saving since 1979. He has donated time and seeds to projects all over the world, especially those in higher elevations.

Bill was cofounder of the Down Home Project and Garden City Seeds in Missoula, Montana, and The International Seed Saving Institute in Ketchum, Idaho. He helped establish the Sawtooth Botanical Garden and has served on the boards of directors of the Northwest Coalition for Alternatives to Pesticides, the Idaho Sustainable Agriculture Committee and The Idaho Humanities Council. He published his first book in 1994 titled, "Basic Seed Saving".

He is currently a member of the Idaho Native Plant Society, The Idaho Watersheds Project and The Alliance For The Wild Rockies. Bill is a native of Ketchum, Idaho and holds a BA in philosophy from the University of Montana.

## LINDA MCMAHAN

### Native Plant Garden: Practices and Recommendations

Linda earned a B.A. and Ph.D. in botany from the The University of Texas at Austin. Following graduation in 1972, she taught at Utica College of Syracuse University. After teaching for four years, Linda left to pursue a law degree, which she completed at Washington College of Law at American University in Washington, DC in 1981.

In years following, Linda worked in the field of plant conservation in the U.S. Department of the Interior, the World Wildlife Fund, and the Center for Plant Conservation, then located at The Arnold Arboretum in Boston. In 1989, this led to a position as Executive Director of The Berry Botanic Garden, a small non-profit botanic garden in Portland, Oregon dedicated to conserving a historic garden, promoting gardening with Northwest Native Plants, and conserving rare and endangered plants through seed banking and research. For seven years in the 1990's, Linda served as Commissioner of Oregon's Department of Environmental Quality, a position appointed by the Governor.

In September 2000, Linda accepted her current position just 30 miles south of Portland in McMinnville, where she is Staff Chair of the Yamhill County Office of OSU Extension, and Associate Professor of Horticulture at OSU, overseeing the county's extensive Master Gardener Program.

## ELLIOTT MENASHE

### Bio-Structural Erosion Control: Incorporating Vegetation in Engineering Designs to Protect Puget Sound Shorelines

Elliott Menashe has been a natural resource management consultant since 1989. He is the owner of Greenbelt Consulting on Whidbey Island. Elliott received a degree in Forest Management from the University of California at Berkeley in 1975 and attended the School of Fisheries at the University of Washington in 1986-87. He is the author of Vegetation Management: A Guide for Puget Sound Bluff Property Owners, published by the Washington State Department of Ecology in 1993. Elliott has also conducted educational programs for several agencies and organizations. His firm specializes in low-impact forestry and rural development, riparian and wetland management, and restoration of degraded sites.

## TODD MOSES

### Geomorphic Aspects of Riparian Area Revegetation and Environmentally-Sensitive Streambank Stabilization

Todd Moses is proprietor of Watershed Applications, which since 1993 has provided specialized services in environmental erosion protection and habitat restoration. Todd has more than 16 years of professional experience in applied land and water conservation. During this time, he has participated in the design and construction of more than 35 environmental channel and bank stabilization projects.

## TOBY QUERY

### Challenges in Large Scale Native Plant Production and Revegetation

Toby Query is a botanic specialist with the City of Portland's Watershed Revegetation Program. He received a B.A. in biology from Macalester College in 1997. He has studied Great Green Macaws in Costa Rica,. Spotted Owls in the Northern Coast range in Oregon as well as bird and plant interactions in Minnesotan oak savannas. Since 1999, Toby has been managing seed collection, propagation and allocation of 800,000 seedlings annually for the Watershed Revegetation Program.

## SARAH REICHARD

### Considerations in the Propagation of Rare Plants

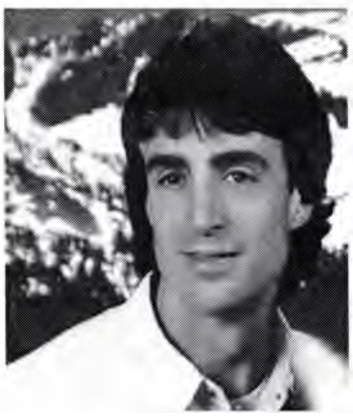
Dr. Sarah Reichard is an Assistant Professor of Conservation Biology at the University of Washington. Her research is focused on in two areas: the propagation and reintroduction of rare species and the understanding the biology of invasive plants, using that understanding to develop risk assessment methods to prevent their introduction and spread. She has worked with the horticulture community for several years to reduce the introduction of invasive species through that pathway. Dr. Reichard is the Secretary of the international Society for Conservation Biology and a member of the US federal government"s Invasive Species Advisory Committee. She also serves on the Invasive Species Specialist Group of the International Union for the Conservation of Nature (IUCN) and is currently completing a study with the National Research Council on science-based methods of risk assessment for plant pests. Dr. Reichard founded and directs the Washington Rare Plant Care and Conservation Program at the University of Washington.

## ROBIN ROSE

### conference organizer and proceedings editor

Robin is the Director of the Nursery Technology Cooperative and the Vegetation Management Research Cooperative at Oregon State University. He received his MS and PhD degrees in forestry from the University of Vermont and North Carolina State University. He has traveled worldwide "preaching the gospel of the Target Seedling Concept" and the need to make better use of modern seedling technology to solve international reforestation problems.

## JOE SCIANNA



### Native Plant and Seed Production for High Elevation Restoration: Growing high elevation species in a northern plains desert

Joe is a Research Horticulturist at the USDA Natural Resources Conservation Service Plant Materials Center at Bridger, Montana. He received a B.S. in Forest Science from the University of Montana and an M.S. in Horticulture from the University of Connecticut. He worked at UCONN Horticulture Research until 1991 when he accepted his current position. Joe is responsible for the woody plant program at Bridger and works primarily on woody plant propagation and tree selection projects. Joe also works on seed production and research projects for Glacier and Yellowstone National Parks.

## JEANIE TAYLOR

### Propagation Successes, Failures and Lessons Learned

Jeanie is a propagator for the Seattle Parks Department. She has a Bachelor of *Science* in Botany with a minor in Conservation of Wildland Resources from the University of Washington. Her previous experience included training in horticulture, operating a field grown cut flower business, and employment in the horticulture industry, with intervals of office work while raising a family. Her lifelong interest in plants and ecology began early while growing up on a cattle ranch in Colorado and New Mexico.

## BARB WILSON

### Genetic Issues in Grassland Restoration in the Willamette Valley

Dr. Barbara Wilson's involvement with grassland management and restoration began twenty-five years ago in Iowa, where she performed plant surveys in native prairie remnants and assisted in controlled burns. Later she helped with two tall-grass prairie restorations, primarily by acquiring seed. In 1992, she moved west to do graduate work on taxonomy and genetics of native fescues (and, less formally, on sedge identification) at Oregon State University. By the time she received her doctorate in this field, she had begun contracting intermittently at the Forest Service's National Forest Genetic Electrophoresis Laboratory, where she analyzed data on genetic diversity of native plants. These diverse experiences have given Dr. Wilson an appreciation of both theoretical and practical problems involved in acquiring seed for grassland revegetation.