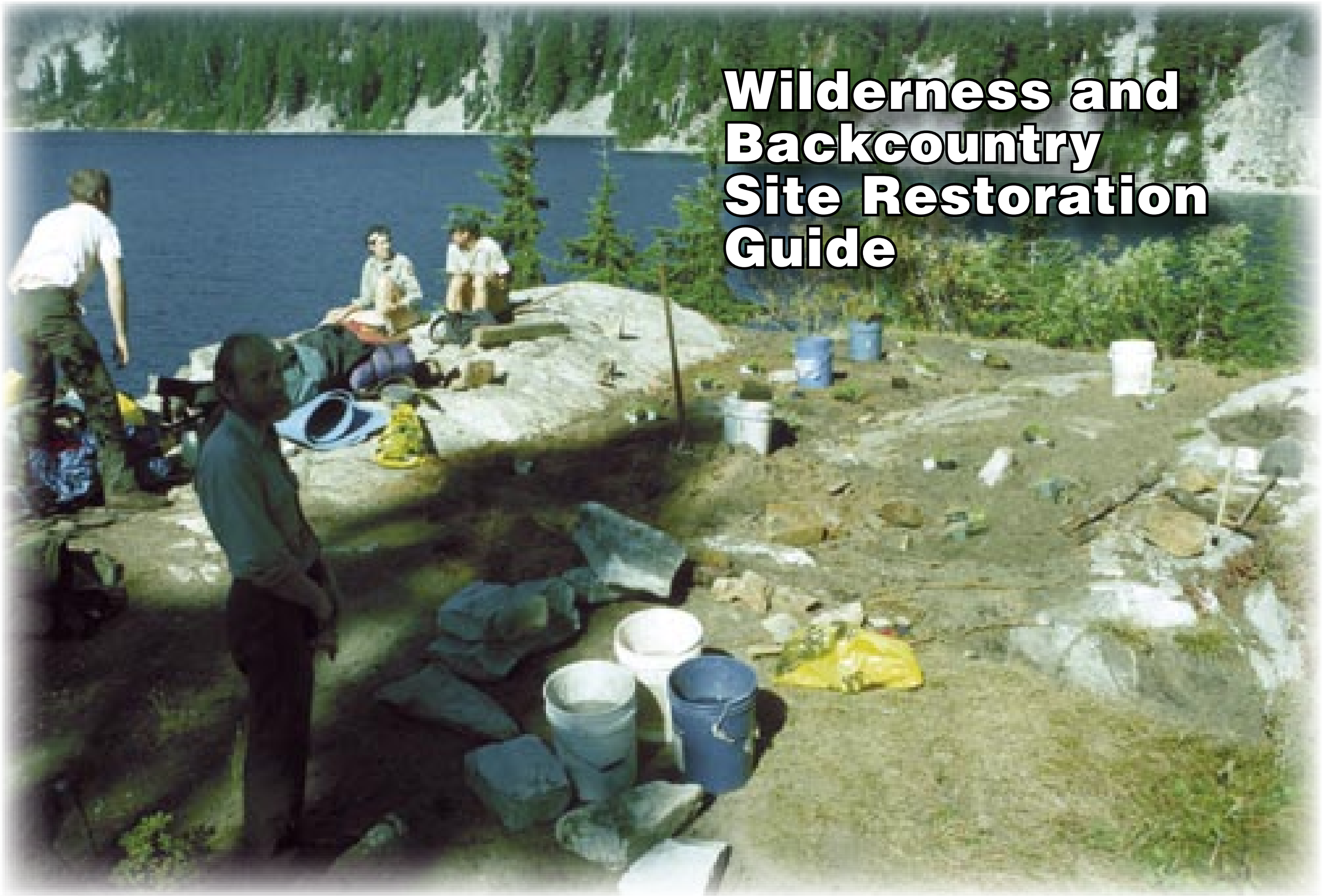
Wilderness and Backcountry Site Restoration Guide



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Planning a well-crafted restoration project in wilderness is like putting together a complicated jigsaw puzzle—after all the pieces from several puzzles have been jumbled together and several of the pieces have been lost in the couch or sucked up in the vacuum cleaner. Writing this guide has been an exercise in furnishing all the puzzle pieces for a successful restoration project—or at least enough of them that any holes left in the puzzle won't create a big problem.

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Introduction

For the past two decades, resource managers have attempted to address the impacts caused by human actions in backcountry and wilderness areas. In some wildernesses, wilderness study areas, and national parks, these impacts are quite extensive: large areas denuded of vegetation, compacted soils, braided trails, and tree roots exposed after horses have been tied to trees. For many reasons, including water quality, soil stability, and esthetics, managers would like to prevent further impacts and help the existing impacts heal.

Wilderness management plans have addressed impacts by establishing desired conditions, indicators, and standards. Indicators such as vegetation loss, tree roots exposed, and the number of social trails are monitored to keep track of changes to the resource. Standards set limits on the amount of change that will be accepted before management action. In some wilderness areas, standards were not being met when the management plan was signed. In such situations, actions must be taken to prevent further resource degradation and to bring the resource back into compliance with standards. A number of actions are possible, one of which is physical restoration of the site. Although restoration is not necessarily the best choice in many situations, restoration can be very effective if it is done properly.

Managers across the Nation have had varying degrees of success with restoration. Some areas, such as the North Cascades National Park in Washington, have had successful restoration programs for years. The North Cascades program includes a greenhouse operation where plants are grown from seed or from cuttings that are collected on the site, carried into the backcountry, and planted. Other areas with fewer resources and less precipitation have not been as successful.

There is no textbook answer that guarantees success in backcountry site restoration. Much restoration knowledge is learned by trial and error. Many, many different techniques have been tried in one area or another, although information about these techniques may not have been passed along. This guide has been developed to facilitate information exchange. It is a compilation of the best information available from researchers and practitioners.

Purpose of This Guide

This guide was developed to provide managers with information that could help them decide whether to attempt restoration and, if so, how to go about it appropriately in wilderness. This guide will help managers share information and exchange ideas.

This guide ***is***:

- Focused exclusively on restoration of small-scale impacts caused by human actions, such as recreation use or removal of administrative or special provisional structures (structures exempted under "Special Provisions" in section 4(d) of the Wilderness Act). Use of the word "site" in this publication refers to any number of small-scale disturbances—not necessarily a campsite.
- Based on the assumption that projects are in wilderness or backcountry settings (figure 1).

Figure 1—Dinosaur National Monument, UT.

- Based primarily on examples from the Western United States—from the Rocky Mountains westward (figure 2). Many of the techniques and procedures apply to any environment.

Figure 2—Henry M. Jackson Wilderness, WA.

This guide ***is not***:

- A guide to large-scale ecological restoration. Human-caused disturbances, such as mining and grazing, have occurred in wilderness at a landscape scale. Large-scale ecosystem restoration is a complex topic. Philosophical questions could be raised about such large-scale restoration in wilderness, where it might be regarded as a form of manipulation or "trammeling." Many large-scale applications need to be designed to meet regulations and engineering specifications that this guide does not address.
- A guide on fire suppression rehabilitation or burned area emergency rehabilitation (BAER).
- A guide to motorized tools or mechanized transportation, although these methods may be mentioned.

Special Wilderness Considerations

The Wilderness Act of 1964 set aside lands in the United States "to secure for the American people of present and future generations the benefits of an enduring resource of wilderness" to be "administered for the use and enjoyment of the American people in such a manner as will leave them [the lands] unimpaired for future use and enjoyment as wilderness…."

Congress further defined wilderness "as an area where the earth and its community of life are untrammeled by man, where man himself is a visitor who does not remain." Wilderness "is protected and managed so as to preserve its natural conditions and which (1) generally appears to have affected primarily by the forces of nature, with the imprint of man's work substantially unnoticeable…."

The Wilderness Act also includes special provisions allowing certain uses primarily because they existed before lands were designated as wilderness. These uses include grazing and mining.

The Wilderness Act's mandate can pose interesting challenges for a wilderness manager who needs to manage for recreation, mining, grazing, and other activities, while keeping "man's work substantially unnoticeable." In some cases, impacts that occurred before lands became wilderness threaten the integrity of the wilderness. Impacts may include vegetation and soil loss, unnecessary structures, and invasive plant populations. Where these impacts exist, managers feel an obligation to do something. Frequently, restoration is the solution that comes to mind.

Agency policies require that wilderness be managed to allow natural ecological processes to operate freely. Management actions should be the minimum necessary to preserve and protect wilderness. The Wilderness Act specifies that wilderness be untrammeled by man. It's appropriate to ask questions such as:

- Is active revegetation of a disturbed site too manipulative?
- Is this action the minimum necessary?
- Do our actions interrupt the natural ecological processes?

Before a wilderness manager begins planning for a restoration project in wilderness, it is critical for the manager to think about the answers to these questions. Restoration does not consist simply of scarifying a site, sticking plants in the ground, and going away for the summer.

Restoration is a manipulative action that deserves a great deal of thought and planning, both to minimize the impacts to wilderness and to increase the likelihood of success. In many situations, the solution is simply to eliminate use at the site and allow the natural process of healing to occur. It is important to question your actions continually to be confident that they are the minimum necessary.

Goals of This Guide

- To provide guidance on developing a plan that thoroughly addresses the question of whether site restoration is the best management action and, if so, how to develop a site-specific restoration plan.
- To provide the latest information on site-specific restoration techniques, including site preparation, soil amendments, planting, mulching, and so forth.
- To explore the various methods of plant propagation both on and off the site.
- To inform managers of the documentation and monitoring required before undertaking a project and for ongoing progress reports.

Target Audiences

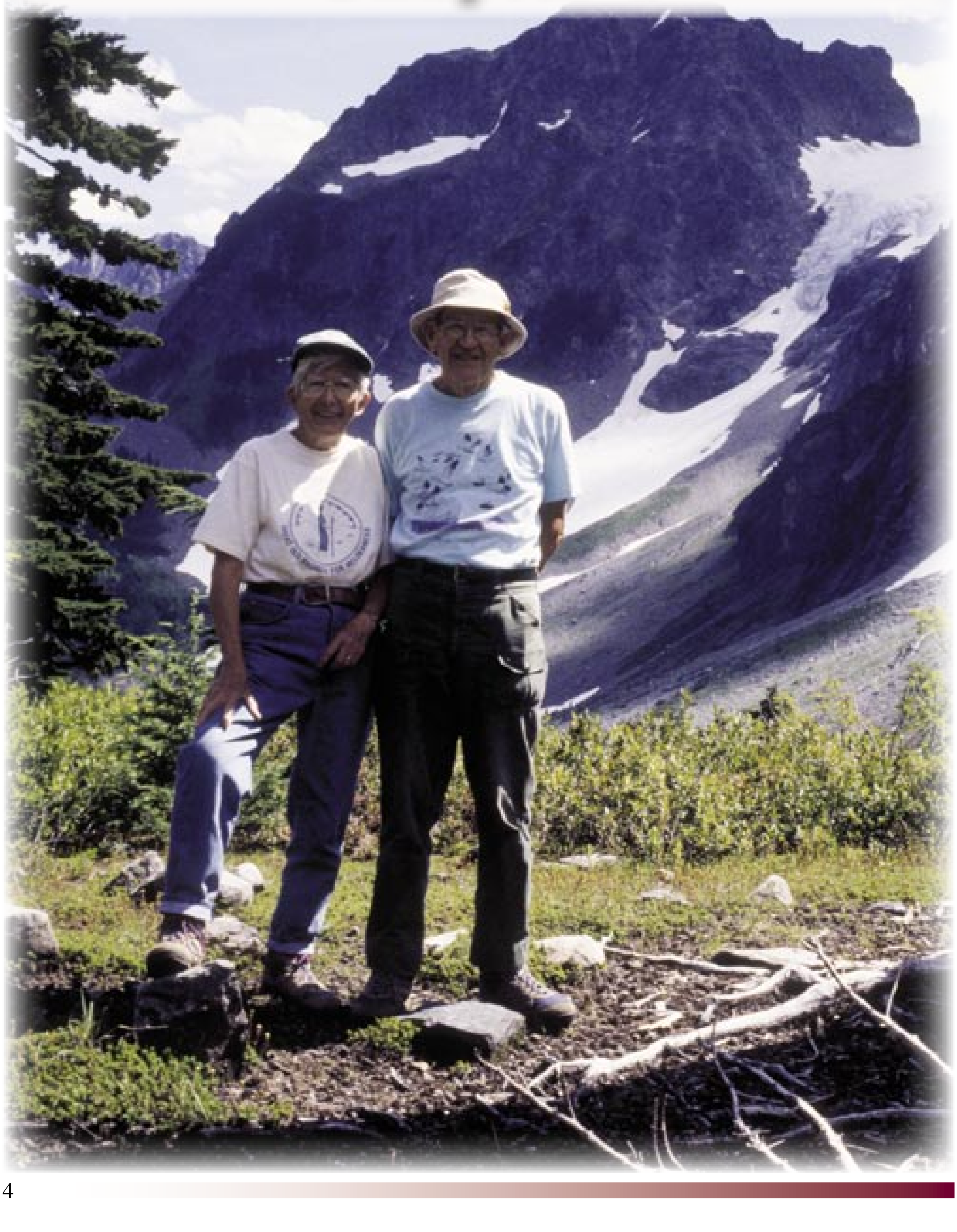
The target audiences for this guide include anyone who plans or implements site restoration in backcountry or wilderness areas or who would like to do so, including wilderness rangers, wilderness managers, resource specialists, recreation planners, or trail crew members. Anyone who reviews restoration plans or advises anyone who implements the plans would benefit from reading this guide.

Nomenclature

Not only common names, but also the scientific names of many plant species have been changing in recent years. An attempt has been made to determine current usage, to determine which of the species discussed in this book has a new name, and to determine whether any name used is authoritative.

One of the easiest sources for help in sorting out common and scientific names is the U.S. Department of Agriculture (USDA) PLANTS database on the Internet at *http://plants.usda.gov*, although this database may not be up to date for all species.

Chapter 1



The Context for Wilderness Restoration

This chapter includes three sections. The first section provides a historical context for wilderness restoration projects. The second section explains the relationship between wilderness impacts and ecological processes. The third section is an overview of the ecological concepts that influence the success of restoration projects.

1.1 Wilderness Restoration in the Past, Present, and Future

The Wilderness Act directs agencies to protect and manage wilderness "so as to preserve its natural conditions," ensuring that wilderness "generally appears to have been affected primarily by the forces of nature, with the imprint of man's work substantially unnoticeable." Although the Wilderness Act does not specifically mention restoration, increasingly managers are turning to restoration to preserve wilderness character. Heavy scars on the land—whether from past practices or ongoing uses—compromise the goals of the Wilderness Act. Restoration (figures 1–1a and 1b) is one way to reduce the scars. Interest in wilderness restoration is at an all-time high.

Figure 1–1a—Cascade Pass in North Cascades National Park, WA.

Figure 1–1b—Since the 1970s and continuing to this day, North Cascades National Park has worked to restore meadows at Cascade Pass using native plants grown in the park's greenhouse.

1.1.1 The Past

It is difficult to trace the true beginnings of wilderness restoration. Recent related efforts consist of attempts to reforest areas of timber harvest, to rehabilitate overgrazed rangelands, and to revegetate roadcuts and other disturbances in parks. In the 1960s, research was conducted on maintaining or restoring vegetation at developed campgrounds (Wagar 1965, Jollif 1969).

In wilderness, most efforts can be traced to the Pacific Northwest and several projects undertaken by the Forest Service and the U.S. Department of the Interior National Park Service, based on the research and recommendations of Dale Thornburgh, a forestry professor at Humboldt State University (1962, 1970). These projects were undertaken in 1970 and shortly thereafter—first in the Glacier Peak Wilderness (figures 1–2a and 2b) and North Cascades National Park and then at Mt. Rainier and Olympic National Parks. By the mid-1970s, wilderness restoration projects had spread to a number of other national parks, such as Rocky Mountain and Yosemite.

Figure 1–2b—By the 1960s unregulated recreational stock use had severely degraded meadows and forested campsites. In response, the Forest Service closed the lake basin to all stock use and overnight backpacker use and began restoration. The lush meadows responded quickly to the elimination of stock use, but the drier shaded campsites have responded slowly to treatments.

Figure 1–2a—Image Lake in the Glacier Peak Wilderness, WA, wasn't always this scenic.

Much of the credit for the blossoming of wilderness restoration in the Pacific Northwest goes to volunteer biologists Joe and Margaret Miller (figure 1–3). In 1970 they were given the task of carrying out Thornburgh's suggestions. They started with a few of his ideas, and developed and tried many more of their own. Concerned managers from neighboring areas adopted the Millers' ideas and developed others.

Many revegetation efforts in Pacific Northwest national parks were documented. It is possible to learn from the early progress of the Millers (Miller and Miller 1979) and other practitioners at North Cascades (Lester 1989), Mt. Rainier (Dalle-Molle 1977), and Olympic National Parks (Scott 1977).

Figure 1–3—Volunteer biologists Joe and Margaret Miller deserve much of the credit for the blossoming of wilderness restoration in the Pacific Northwest. [This photograph was digitally altered to remove distracting elements.]

1.1.2 The Present

Restoration appears to have become one of the jobs of wilderness management. The number of wilderness rangers with rudimentary site restoration skills is increasing rapidly. Many national parks now have greenhouses or nurseries. Restoration skills are being taught both by agencies and by outside specialists, such as the Student Conservation Association.

The most important lessons of site restoration have been:

- Practical methods for restoring damaged sites
- Improved perspectives on restoration's role in wilderness management

1.1.2a Practical Methods of Restoration

The initial restoration projects in the Pacific Northwest usually involved transplanting plugs of vegetation from neighboring areas. This technique, while simple and generally successful, affects adjacent areas. It is impossible to find much material for revegetation without causing substantial impacts elsewhere. This problem has been alleviated by off-site propagation and improved methods of revegetation from seeding.

At North Cascades National Park, the Millers pioneered the technique of removing plant plugs from the field, dividing and growing them at low-elevation greenhouses, and transporting plants back to the damaged site for planting. This technique was effective, but costly and time consuming. Moreover, it had the added disadvantage of reducing the genetic diversity of the population because all individuals were clones of a few original plants.

Some of these problems were overcome when workers discovered effective means of propagating plants from seed in the greenhouse. Now it is possible to collect seed in the field, germinate these seeds, grow plants in the greenhouse, and then transplant the seedlings to the field. The key to successful germination of subalpine plants includes sunlight, high humidity around the seed, and high soil temperatures (Lester 1989). Through trial and error, workers have come up with more effective means of propagating difficult species, such as the heathers.

In some parts of the country, such as the Colorado Rocky Mountains, rangers have had considerable success using direct seeding to revegetate damaged sites. However, in the Pacific Northwest, seeding has been used effectively only in recent years. Through trial and error, managers found that seeds would germinate in abundance if they were kept warm and moist. The key was to cover the site with polyethylene sheeting (Visqueen). Difficulties still remain, such as the cost of collecting seed. Generally, seeding will be the most cost-effective means of revegetating damaged sites.

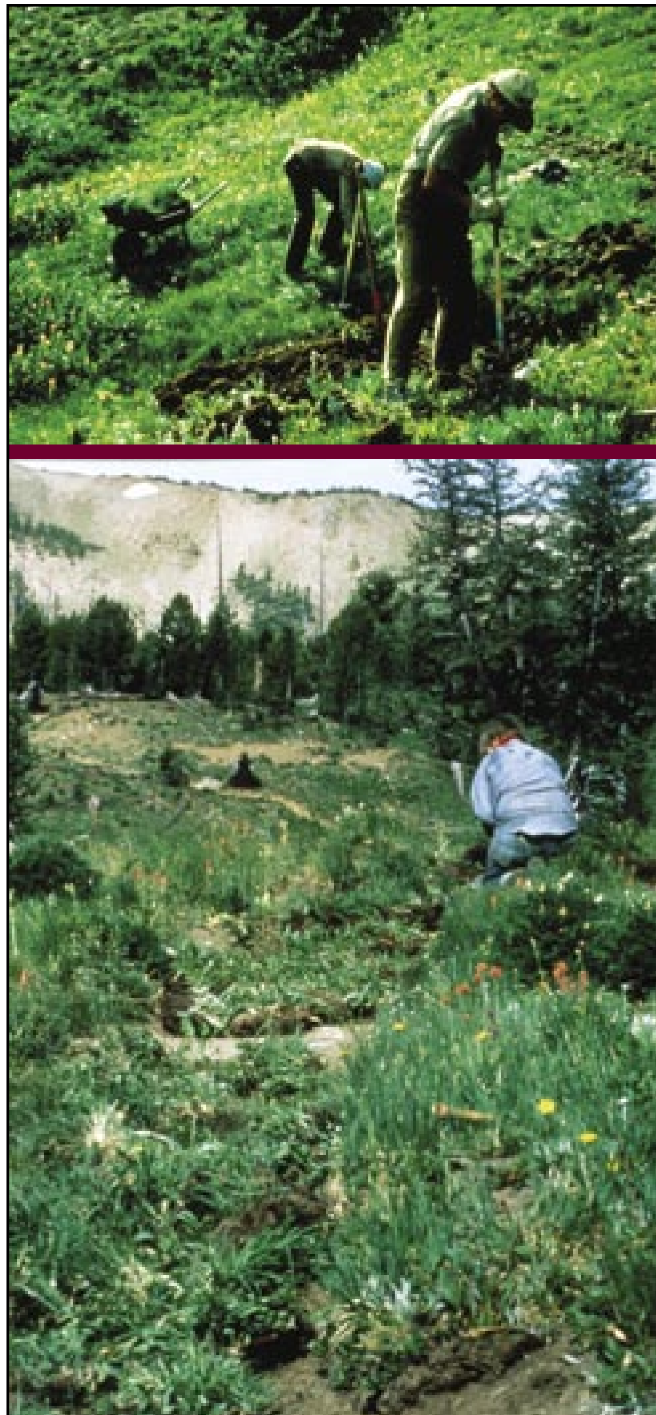
Progress also has been made in understanding the importance of mulches, which help retain moisture and prevent seeds from blowing or washing away. While native mulch is the best option, commercial mulches are often a more feasible alternative. Initially, jute netting was the most commonly used mulch. However, jute often decomposed too slowly, was too obtrusive, and entangled emerging plants. Jute is still used, but practitioners now use a wider variety of mulches that can be tailored to individual needs.

Most of these advances in technique were made through trial and error. A few individuals experimented with different techniques, monitored the effectiveness of each technique, and communicated what they had learned to others. It is imperative that all of us continue this process. This means we must experiment, document, monitor, and communicate our successes and our failures.

1.1.2b How Restoration Fits With Wilderness Management

Any time visitor use is shifted, impacts will shift as well. New impacts are created, while scars from old impacts may remain. These scars should be healed as quickly as possible. For example, restoration should be an integral part of trail relocation programs. Eroded trail segments frequently are abandoned without rehabilitation when trails are relocated. Restoration should be part of the original trail reconstruction plan. Building a trail may leave a substantial amount of soil and plant material that can be used to revegetate old tread (figures 1–4a and 4b). The key is to time the work and to have resources available to use the soil and plant materials as they become available.

In many wildernesses, camping is prohibited near lakeshores, where the impacts of past use are pronounced. This prohibition often has been ineffective and managers may have expended little effort trying to enforce it. If management is serious about a lakeshore setback, restoration should



Figures 1–4a and 4b—If the vegetation type matches, plugs of sod salvaged during trail relocation (top) can be used to restore (bottom) an abandoned section of trail.

be part of the program. Because the impacts of visitors will be extended into new areas farther from the lakeshore, it is important to restore at least some of the lakeshore. Restoration generally will require keeping all use (not just camping) off the restoration sites for a substantial period. One way of proceeding might be to fence off 20 percent of the lakeshore until that area has been restored and then move to the next 20 percent of the lakeshore. It might take 100 years to restore the lakeshore, but at least restoration could occur.

As we become more aware of the decades required for restoration and the difficult odds that must be overcome, some workers are becoming more conservative. Increasingly, they decide that it may be better to allow an impacted area to continue being used than to move that impact elsewhere while attempting to restore the old site. Or they decide to restore the fringes of damaged sites (figures 1–5a and 5b), reducing the size of the area being damaged without moving use elsewhere.

Figure 1–5a—The margin of this campsite was revegetated with locally native plants grown in a greenhouse. The flat portions of the site remain open for camping at Little Caroline Lakes in the Alpine Lakes Wilderness, WA.

Figure 1–5b— This trail at Lake Mary was narrowed using rocks so the margins could be restored.

Restoration should be undertaken only when adequate resources are available and success is likely. The causes of the impacts must be identified and a feasible means of keeping the impacts from recurring elsewhere must be laid out. Preventing impacts usually involves a variety of visitor management techniques, from access restrictions to visitor education. Site restoration becomes just one technique among a suite of techniques needed to deal with impacts.

1.1.3 The Future

We do not have a crystal ball allowing us to predict the future. However, if current trends continue, the future of site restoration in wilderness will bring:

- More specific skill development
- An increase in holistic planning

1.1.3a Skills Development

The blossoming of restoration ecology as a discipline, along with the acceleration of wilderness restoration, should lead to dramatically improved restoration skills. The rate of improvement will depend primarily on the rigor that goes into experimentation and documentation of restoration trials. Everyone can contribute to the long-term success of restoration techniques by documenting their restoration projects and communicating their results.

Often, nurseries and greenhouses are being used as restoration tools. Techniques for propagating species that are difficult to grow are being developed. More commercial nurseries are taking an interest in native species and more volunteer organizations are available to help.

1.1.3b Holistic Planning

A good plan doesn't guarantee a good project, but it can help. Plans are likely to improve in comprehensiveness, scale, and integration. In the past, most restoration plans dealt primarily with the specific techniques that were used to get plants growing on the site again. Increasingly, we are seeing plans that start with goals, assess constraints, set targets, and monitor success in relation to these targets. Such programs are more likely to be successful and are more likely to help us learn from the failures that inevitably occur.

In the future, planners are more likely to:

- Consider one specific site in the context of larger areas or even an entire wilderness.
- Link site restoration to other management actions needed to keep problems from recurring or simply being shifted elsewhere.
- Recognize the long timeframes that generally are required, such as the more than 20 years needed to restore Cascade Pass (figures 1–6a and 6b) in the North Cascades.
- Consider issues of genetics, which were given little thought a decade or two ago.

Finally, future plans will do a better job of integrating people and ecosystem management. Research on visitors and visitor management is as important to success as research on plant propagation and site management. An excellent example of planning that integrates people and ecosystem management is the work done to rehabilitate Paradise Meadows at Mt. Rainier (Rochefort and Gibbons 1992). Ecosystem management is a recent buzzword, but the interdisciplinary approach it implies is critical to the success of wilderness restoration.

Figures 1–6a and 6b—These photos, taken 28 years apart, show the effects of restoration at Cascade Pass in North Cascades National Park, WA.

1.2 Impacts of Recreation and Similar Small-Scale Disturbances

There is always a tendency to jump into a restoration project. The impacts are obvious and the desired outcome is easy to visualize. This section describes the nature of site impacts and discusses the types of impacts that are likely to be considered problems. An understanding of site impacts guides decisions about the site conditions and processes that need to be repaired. Problem definition makes it possible to measure success and also helps set priorities for projects.

For restoration to be a long-term success, it is important to:

- Understand the nature of impacts caused by recreational use.
- Decide which impacts are significant problems that require restoration.
- Identify the causes of those problems.
- Devise ways of changing visitor use so that the problems do not recur.

The planning process and management techniques described in chapter 2 address these issues.

Management techniques focus on identifying the causes of problems and selecting management actions to decrease the likelihood that problems will recur or simply be shifted elsewhere.

1.2.1 What Are the Impacts of Recreational Use?

This discussion of the impacts caused by recreation use is divided into linear impacts, such as those caused by trails (figure 1–7), and the impacts of concentrated use on larger sites. Trails are linear and may run up and down steep slopes, making them susceptible to erosion. Impacts of primitive roads are similar to those of trails. Recreation sites—campsites, picnic sites, vista points, or popular fishing spots—have a different pattern of impacts caused by people or animals that trample one spot. These sites usually are relatively flat and, in most wilderness areas, are created by users. Impacts around administrative improvements, such as water guzzlers for wildlife, and around other areas of concentrated use have impacts that are similar to those around campsites.

Figure 1–7—Recreational use that exacerbated past damage from sheep grazing was responsible for these parallel trails in the Selway-Bitterroot Wilderness, ID.

1.2.1a Trampling

At recreation sites, most of the damage that requires restoration is caused when visitors or their stock trample vegetation. If the damage is light, most plants may survive, even though their height, vigor, and reproductive capacity may decline. If the damage is more severe, certain plants may be killed. Vegetation cover will decline and species composition will change. If the damage is severe, all plant cover will be eliminated. This is the situation that most frequently confronts the restorationist.

Trampling also affects soil characteristics (figure 1–8). These changes further degrade the vegetative community. Trampling disturbs the soil's organic horizons, the dead and decomposed plant matter that form the uppermost layer of most soils. If the disturbance is pronounced, the organic horizons may be lost completely. Loss of surface organic horizons makes the underlying mineral soil horizons more vulnerable to compaction and erosion. It also can reduce the amount of organic matter that becomes incorporated into the soil, leading to a number of detrimental effects. Organic matter promotes the aggregation of soil particles into clumps, increasing the soil's ability to retain water and nutrients. Aggregation allows proper soil aeration and promotes root elongation and growth. Organic matter is particularly important to water and nutrient retention in sandy soils. Without organic matter, these soils may be susceptible to drought and become infertile.

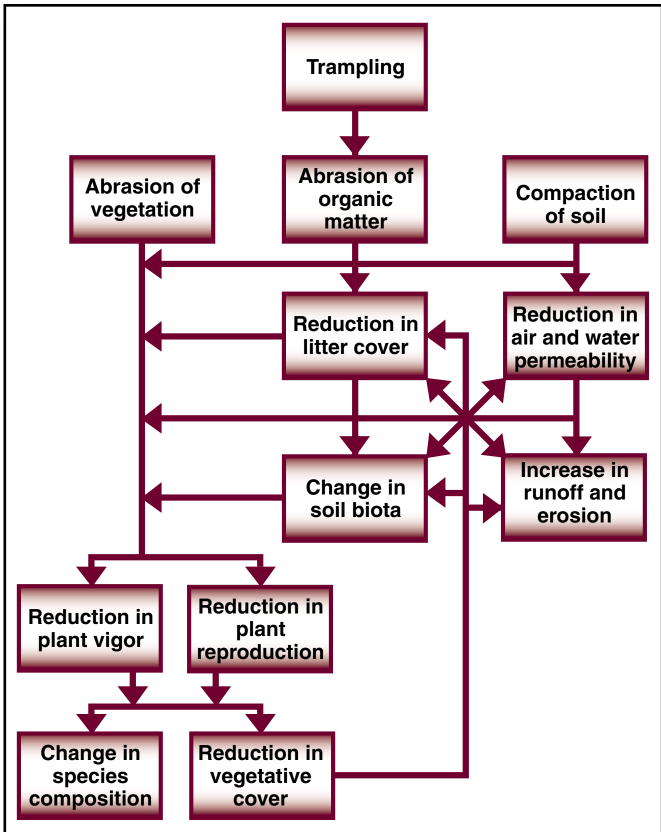


Figure 1–8—A conceptual model of trampling effects, based, in part, on Liddle (1975) and Manning (1979).

Trampling also compacts the underlying mineral soil. Normally, less than half the volume of soil is solid matter; the rest is pore space occupied by air and water. Compaction presses soil particles close together, eliminating pore space, particularly the larger pores that allow water to percolate rapidly after rain. By decreasing the permeability of the soil, compaction can increase surface runoff and erosion.

Generally, compaction reduces water availability to plants, but in certain situations, compaction can increase a soil's water-holding capacity, increasing water availability. Reduced soil aeration can shift conditions from aerobic to anaerobic, creating an environment that is less favorable for soil biota, including mycorrhizal fungi. These changes adversely affect nutrient cycling.

Compacted soils often are so smooth that they offer no safe sites where seedlings can germinate and establish successfully. Rough surfaces have small depressions that collect moisture and organic matter, increasing the chance that seeds will lodge there and contact the soil. Even if seedlings become established in compacted soils, plant growth may be limited because it is difficult for roots to penetrate soils with low porosity.

The conceptual model of trampling impacts shows that some ecosystem components are affected along multiple pathways and that there are numerous positive feedback loops (vicious cycles). Populations of soil biota are altered by all three of the direct effects of trampling—elimination of vegetative cover, loss of surface organic horizons, and soil compaction. Loss of vegetative cover eliminates the primary energy source of soil microbes; loss of organic horizons eliminates another energy source; and compaction reduces pore size and aggregation, influencing critical habitat characteristics, such as the mobility of water. Even if just one or two of these impacts can be dealt with effectively, soil biota will benefit.

1.2.1b Trampling Damage to Ecosystem Components

Positive feedback loops are of particular concern because impacts may continue to intensify even if disturbance from the original source has been reduced. One positive feedback loop involves soil compaction, erosion, and litter loss. Soil compaction reduces porosity and rates of water infiltration. Runoff increases, increasing erosion of mineral soil and organic horizons. Loss of organic horizons aggravates compaction problems, leading to more erosion, and so on.

Another cycle involves loss of vegetation, soil organic matter, soil biota, and favorable conditions for plant growth. Loss of vegetation removes a major source of organic matter. Reduced organic matter leads to changes in the soil biota and less favorable conditions for plant growth. With less plant growth, vegetation cover declines further, organic matter inputs to the soil decline further, soil conditions decline further, and so on.

Compacted soils, loss of organic matter, and altered soil biotic populations lie at the center of many of these vicious cycles. Perhaps the most critical task for the restorationist is to mitigate impacts to these ecosystem components and break these vicious cycles of impacts.

Many different ecological changes, working together, contribute to the lack of vegetation on a disturbed recreation site. Even if recreation use is eliminated, the changes to the soil may prevent vegetation from becoming reestablished. Plants may not flourish because soils have been altered so severely. For the system to regain its normal function, soil organic horizons, soil biota, and soil structure all need to be repaired. Making soils more receptive to plants—by improving soil structure and biotic communities—may be more important than introducing plant propagules, such as seeds or cuttings.

1.2.1c Campfire-Related Impacts

Impacts associated with collecting and burning wood in campfires aggravate problems caused by trampling (Cole and Dalle-Molle 1982). The removal of fallen wood further reduces sources of soil organic matter. Removal of large decaying wood is particularly detrimental. Large woody debris has an unusually high water-holding capacity; stores nitrogen, phosphorus, and sometimes calcium and magnesium; and serves as a significant site for the establishment of nitrogen-fixing micro-organisms and mycorrhizal fungi. When wood is burned in a campfire, soil organic matter, nitrogen, and microbes all are reduced dramatically. Special attention may be required when rehabilitating firerings at campsites or at other areas where soils have been altered.

1.2.1d Damage to Standing Trees

Damage to standing trees is another common impact at campsites. Campers damage trees by:

- Tying horses to them (figure 1–9)
- Cutting down saplings for tent poles or firewood
- Carving initials in their bark
- Hacking them with axes
- Pounding nails into them

If trees are not chopped down or girdled, usually they can survive injuries, even though their vigor may be reduced. Opportunities to reverse damage are limited. However, if the behavior of recreational users can be changed, additional damage can be prevented.

Figure 1–9—Trees damaged by stock pawing the ground at Lake Augusta in the Alpine Lakes Wilderness, WA.

1.2.1e Trail Impacts

Trampling also occurs on trails. When trails are constructed, vegetation and organic matter are removed, and soils are compacted. These impacts are intentional and make the trail convenient to use. When trails need to be restored, the impacts of trampling and trail construction must be repaired. In areas where trails cross slopes, construction commonly leaves a cutbank above the trail and some fill material below the trail. When a trail is restored, often fill should be pulled back on the trail to reestablish the original contour. This is particularly true for primitive roads.

Trails may intercept drainages. Problems with erosion (figure 1–10) may be particularly severe in such areas. It is not unusual for several feet of soil to have been lost on or

Figure 1–10—A deeply incised trail at Lake Valhalla in the Henry M. Jackson Wilderness, WA. Once an erosion channel forms, water—rather than foot traffic—causes most of the damage.

along trails, exposing lower soil horizons, which typically are less capable of supporting vegetation. Soil structure is less developed in the subsoil. Organic matter and soil biota are negligible. Restoring productive soil processes is particularly challenging. In areas where it is possible, trails should be filled with topsoil to bring them back to grade.

Another problem with trails is that once drainage systems have been disrupted, erosion can continue even if the trails are no longer used. Once trails become lower than their surroundings, water tends to be channeled down trails. The first priority of trail restoration is to deal with drainage and erosion problems.

1.2.2 Which Impacts Should Be Considered Problems?

Problems on campsites and other sites that receive concentrated use (picnic sites, vista points, fishing spots, and so on) are relatively easy to define. Any site that has been substantially altered by humans could be considered a problem. But such an approach is not tenable. With repeated use, mineral soil will be exposed, compacted, and inevitably lost. Numerous studies have shown that substantial impact occurs within a short time, even with relatively light camping use (Cole 1987). We must accept that any sites that receive repeated use will be substantially impacted. In these places, managers can more effectively control the number and distribution of impacted sites than the level of impact on individual sites.

At popular wilderness destinations, the most appropriate objectives for a site restoration program are to reduce the number of impacted sites (figure 1–11) or to eliminate sites in undesirable locations. For instance, a restoration program

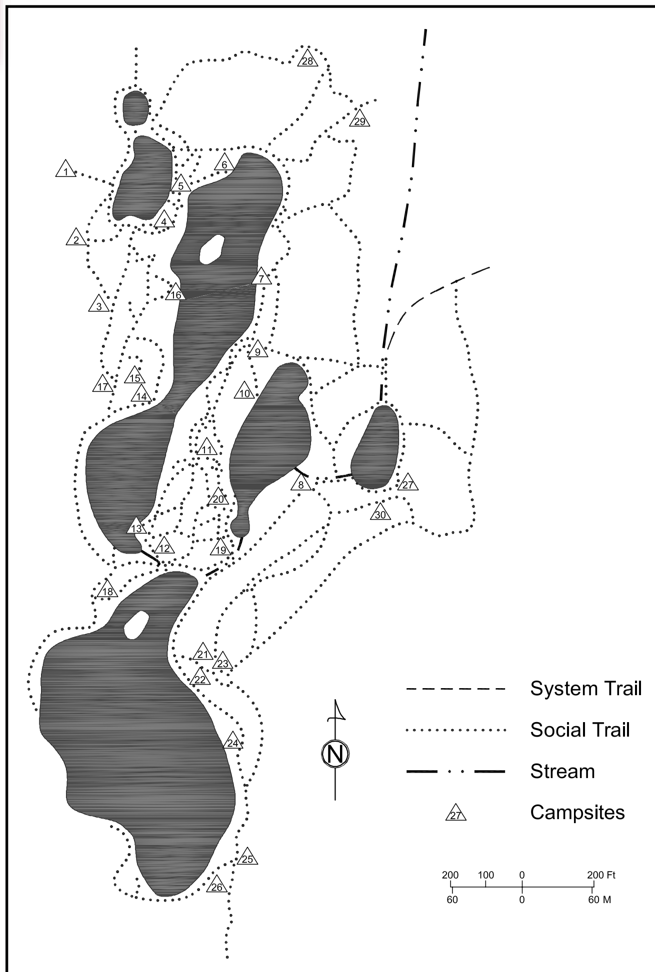


Figure 1–11—This map shows impacts around Rampart Lakes in the Alpine Lakes Wilderness, WA. In such cases, it is easier to reduce the number of trails and sites that are being impacted than it is to reduce the severity of impact on any particular trail or site.

could be beneficial in areas where campsites are too close to lakes or other fragile locations. In remote, lightly used areas, it may be desirable to attempt to close and restore all sites that show signs of use and impact. But in other areas, it is probably not reasonable to close sites simply because they have been altered substantially.

The problems caused by user-created (social) trails and off-trail routes are similar. Wherever consistent use occurs, these impacts cannot be eliminated (figure 1–12). The most realistic options are to keep trails to a minimum and to try to eliminate them in undesirable locations. When deciding which trails to eliminate and which to keep, carefully consider people's desires (where they are trying to go) and the physical constraints that affect trail development (such as snowmelt patterns or the visibility of sites from the trail).

Figure 1–12—Will restoration of these social trails meet with success? Probably not, because the lakeshore and big rock are magnetic attractions in the Enchantment Lakes Basin in the Alpine Lakes Wilderness, WA.

Restoration may be considered when a road or constructed trail is being relocated or decommissioned. Restoration also is appropriate when users have created multiple or shortcut trails. The initial goal of restoration is to eliminate further use of the road, trail, or shortcut. Longer term goals involve restoring the natural topography and plant communities.

The reasons why recreation site impacts are considered problems are more likely to be anthropocentric (based on human preferences) than biocentric (based on biology). Campsites may be considered to be too close to each other or too large. Trails may be considered to be too muddy, too rocky, or too rutted—problems for humans, but not for nature. By carefully defining why we consider problems to be serious (and in need of restoration), we are more likely to make good decisions about what we are trying to accomplish and how we should invest our limited restoration resources. Also, it is helpful to get input from the public.

Our goals must be articulated carefully. Restoration implies trying to return a site to its historical condition, making it like it would have been before it was affected by recreation. If rare or highly vulnerable species have been lost, this goal may be unrealistic. In such cases, rehabilitation may be a more feasible goal. In situations where it is impossible or undesirable to restore species composition and structure (Society for Ecological Restoration Science and Policy Working Group 2002), the goal of rehabilitation is the repair of ecosystem processes. There may be cases where reclamation is the most appropriate goal. Reclamation attempts to stabilize terrain and return it to a useful purpose (Society for Ecological Restoration Science and Policy Working Group 2002). In other cases, revegetation—establishing native species on an abandoned trail or around the periphery of a campsite that is still in use—may be the only realistic goal.

Good sources of additional information on the impacts of recreation include Cole (1987), Hammitt and Cole (1998), and Liddle (1997).

1.2.3 Alternative Management Techniques

Site restoration is just one of a number of management techniques that can be used to address wilderness impacts (Cole and others 1987; Hendee and Dawson 2002). It is important to recognize the broad array of techniques that are available and to understand how restoration fits with other techniques. Restoration treats the symptoms rather than the root cause of problems. If sites cannot be managed in a way that reduces the damage, they can be restored endlessly without making any substantial progress. This makes no more sense than constantly picking up litter without simultaneously working to convince people not to litter. It is critical to understand the primary management actions that must be undertaken before considering restoration.

The effectiveness of alternative management practices can be assessed by understanding why certain sites and trails become severely impacted while others do not. Four factors that can influence the severity of impacts are:

- Amount of use
- Type of use
- Environmental conditions
- Spatial distribution of use

Managers can manipulate each of these factors when attempting to reduce impacts.

The amount of use often has been considered the most critical of these factors. Frequently, managers use terms such as overused and used beyond its carrying capacity to describe a seriously impacted site. Most studies of campsites suggest that the amount of use a site receives is seldom the most critical factor in determining whether impacts at a site represent a problem or not (Cole 1987). Even relatively infrequently used sites can have serious problems. The amount of use does not explain much of the variation in impacts, except when very lightly used campsites are compared.

The same principle applies to trails. Trail segments with problems frequently alternate with segments that are in good condition. Because the amount of use is relatively constant along the trail, something other than the amount of use must explain these differences. There are few situations where reducing the amount of use by itself will reduce impacts substantially.

More variation in the amount of impact can be explained by the type of use and visitor behavior. Large camping parties are likely to create larger campsites than small parties. Parties that have campfires cause impacts that parties using cooking stoves do not. Parties that travel on packstock cause impacts that travelers on foot do not. Hikers who shortcut trails or leave the trail tread cause impacts that hikers who are careful to keep to the main tread do not. Many—but not all—problems result from inappropriate behavior. Large campsites, excessive tree damage, and multiple parallel trails are examples of such problems. These problems can be reduced by changing the behavior of visitors, either through regulation or education.

Other problems result primarily from the location of use. Sometimes trails and campsites are located in particularly fragile environments. For example, problems commonly occur where trails traverse soils that are saturated with water. Trails along fragile shorelines also may affect ecological values. Cole (1995a) has shown that some vegetation types are 30 times as tolerant of trampling as other vegetation types. More often, the problem is the desirability of the location rather than its fragility. For example, campsite impacts are more visually obtrusive in meadows than forests, even though meadow vegetation is generally more durable than forest understory vegetation.

Campsites also may be located too close to each other or to the main trail. These campsite and trail problems can be eliminated by shifting use to more durable locations or to locations where the impacts cause less disturbance.

Finally, total impact will be influenced by whether use is spread across a large area or concentrated. Increasing the concentration of use will increase the impact on individual sites while decreasing the total number of impacted sites. In popular places, total impact is generally minimized when recreation use is concentrated. In remote areas, impacts sometimes can be kept to negligible levels if use is dispersed widely (Cole 1994).

Often the most effective management programs combine different management techniques. For example, when the amount of use is reduced, it will be easier to confine use and impact to a few sites. Use limits must be accompanied by controls on the distribution of use, such as a system of designated campsites.

1.2.4 Incorporating Restoration Into Management

Site restoration is most helpful as part of a management program (Hendee and others 1990) designed to keep problems from recurring or simply being shifted elsewhere. Two conditions of a successful restoration project are:

- Effectively closing the site—getting people to move elsewhere
- Finding a better location for the use—one that is either more durable or in an area where impacts are less objectionable

These conditions are not always met. Often a lakeshore may be closed to camping, but picnickers or anglers continue using old campsites that do not recover. Often, trail segments are closed because of damage, with use being shifted to an adjacent segment that soon is damaged as badly as the original. In either case, impacts proliferate because new areas are damaged while old sites recover slowly, at best.

Restoration is most appropriate in areas with too many campsites or trails and where sites or trails are poorly located. When an area has too many campsites or trails, restoration efforts should be supplemented with a policy that requires camping at designated campsites or with an educational program that encourages use of well-established campsites and trails (figures 1–13a and 13b). Site designation also is a means of encouraging use of durable or preferred locations. Suggesting preferred campsite locations as part of an educational program is a more light-handed approach than requiring use of designated campsites.

Figure 1–13a—Designating campsites is one technique that can be employed to successfully reduce users' impacts.

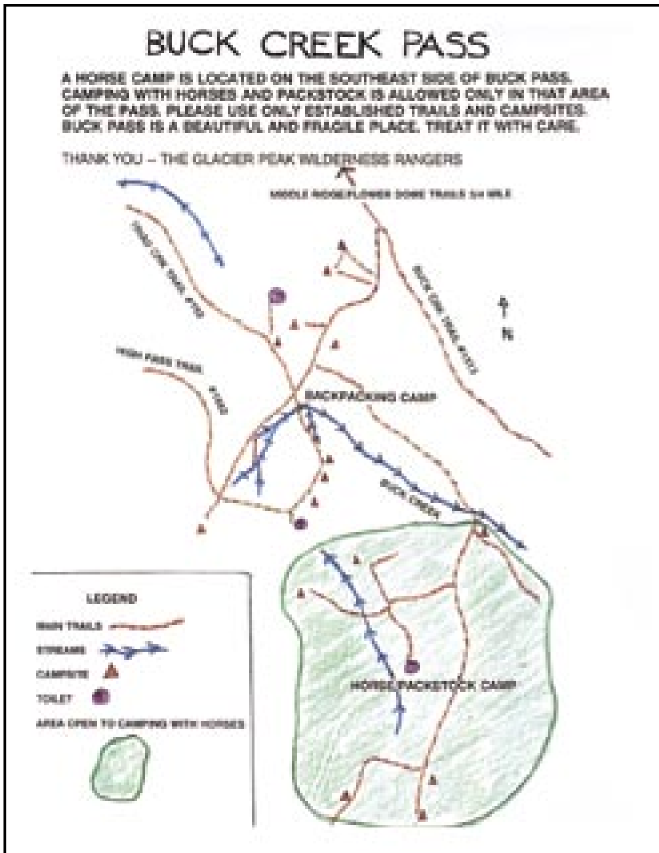


Figure 1–13b—This map (b) shows a camp for stock users at Buck Creek Pass in the Glacier Peak Wilderness, WA.

The success of most restoration projects will depend on the success of supplemental management actions, particularly those actions designed to change the behavior of visitors or the distribution of use. Visitors must be kept off sites that are being restored so the sites have a chance to recover. Closure notices should be conspicuous in the vicinity of the closed site. Visitors are more likely to comply with closures if the reasons for the closure are explained and if visitors are directed to alternative sites that are equally desirable. Visitor behaviors also need to be changed so that the original problems do not recur.

These visitor management actions are a more critical part of the restoration plan than the planting of vegetation. An effectively closed site will eventually recover, whether it is planted or not. But a site that continues to be used will never recover, even if it has been planted.

Without considerable thought and care, the success of restoration projects can be limited. In the worst case, restoration projects may actually increase impacts by shifting use and problems to undisturbed locations. The likelihood of a successful restoration project can be increased by:

- Trying to define the problem that the restoration project is designed to solve
- Attempting to identify what caused the problem (and whether it will recur or be moved elsewhere)
- Implementing supplemental management actions that will complement the restoration project

These measures should be an integral part of a restoration plan, which will be discussed later.

1.3 Overview of Plant and Soil Ecology

Restoration has been called the acid test of our ecological knowledge (Bradshaw 1993). We should be able to judge the quality of our ecological understanding by the success of our restoration programs. Restoration allows us to check whether our ecological theories work. We would be foolish if we did not use our ecological insights as fully as possible in our restoration programs. The following sections provide a brief overview of ecology as it applies to site restoration. Chapter 3, which focuses on restoration techniques, will explain how to apply the ecological principles in this chapter to your project design.

1.3.1 Environmental Components

Restorationists need to understand various components of the environment and the restrictions and opportunities they present. Of particular importance are soil, plant characteristics, microclimate, and animals. See appendix A, *Treatments To Manage Factors Limiting Restoration*, for suggestions on managing environmental limitations when designing restoration projects.

1.3.1a Soil

Soil is much more than an inert medium providing structural support for plants. Soil consists of mineral and organic matter (dead and alive), water, and air. Mineral and organic particles are packed together, but pores between these particles account for as much as 50 percent of the soil volume. Smaller pores (micropores) typically are filled with water, while the larger pores (macropores) are filled with air, except immediately after a rain. The soil provides a home for many organisms other than the plants we see growing on its surface. Microscopically sized organisms and larger organisms (such as earthworms) live in and move through the soil.

Soil is constantly changing. It develops over hundreds to many thousands of years through the influences of biological and inorganic processes at the Earth's surface. Hans Jenny identified five distinct factors that contribute to soil formation: climate, biological organisms, relief or topography, parent material or geology, and time (Jenny 1965). Because each of these factors can vary independently, soils can vary across the landscape. The variation can occur by location or landscape position, and also with depth below the ground surface.

Soils that develop in wet climates differ substantially from those that develop in dry climates. The soils of cool climates also differ from those of warm climates. The soils that develop under grasslands differ from those that develop under forests. Soils also are influenced by the types and abundance of soil organisms and litter. Soils on steep slopes that are prone to erosion differ from those on gentle slopes and those in locations where sediment and debris are deposited. The parent material has much to do with soil texture and soil chemistry. Finally, the time soils have had to develop influences soil mineralogy, soil structure, and the amount of organic matter in the soil.

An understanding of soils and their characteristics is important when assessing the effects of disturbance and when designing a strategy to mitigate those effects. The physical, chemical, and biological characteristics of soils can be disturbed.

Soils typically are organized as a series of layers termed *soil horizons* (figure 1–14). The uppermost horizons are

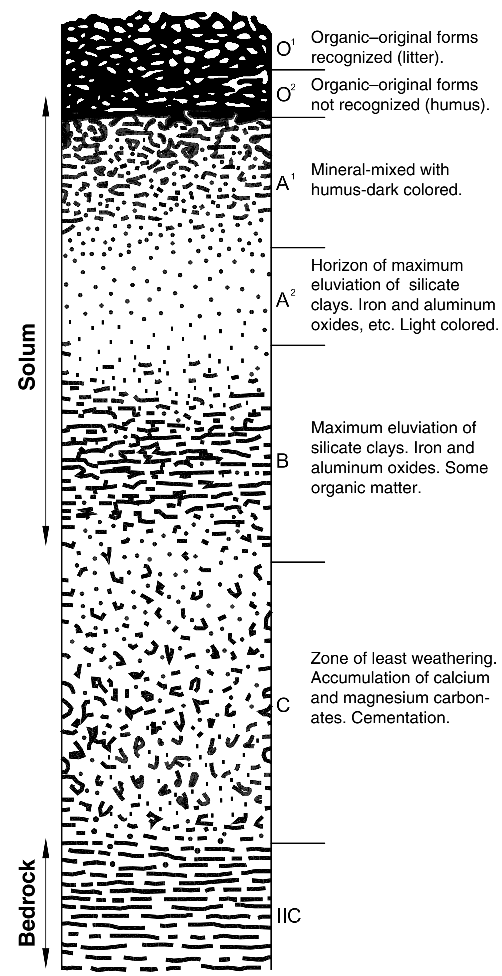


Figure 1–14—An idealized representation of soil horizons. The combined A and B horizons are called the *solum*, or *true soil*.

organic horizons that consist of partially to completely decomposed organic material (the litter of dead plants). These horizons shield the underlying mineral soil from forces that compact or erode the soil. Surface organic matter continues to decompose and move downward into the soil with rainwater. Below the organic horizons are the largely mineral soil horizons. Usually, three horizons are recognized (A, B, and C), although these horizons can be further subdivided or may be missing in certain soils. From the top (A horizon) to the bottom (C horizon), organic matter generally declines. Minerals, small soil particles, and organic materials are often leached from the A horizon and deposited in the B horizon.

Restorationists should study the soil horizons of an unimpacted site, or reference site, which represents the condition of the impacted site before it was disturbed. The impacted site is compared with the reference site to identify whether soil horizons have been lost. Usually, the organic horizon is lost. The darker A horizons (see figure 1–14) or clay-rich B horizons also may be gone. If soil development on the reference site is minimal, restoration can proceed without intensive soil treatment on the impacted site. Considerations for selecting a reference site or sites are described in more detail in chapter 3.

Soils vary greatly in their mix of soil particles of different sizes. This mix influences soil behavior and appropriate restoration procedures. Size classes are:

- Clays—smaller than 0.0001 inch (0.002 millimeter) in diameter
- Silts—0.0001 to 0.002 inch (0.002 to 0.05 millimeter)
- Sands—0.002 to 0.08 inch (0.05 to 2 millimeter)

Rock fragments larger than 0.08 inch (2 millimeters) are not considered soil particles, although they can be incorporated into the soil.

Soil texture is determined by the mix of particle sizes (figure 1–15). Sandy soils typically are well drained, droughty, and infertile. They are not highly susceptible to compaction, but they are erosive. Silty soils typically absorb

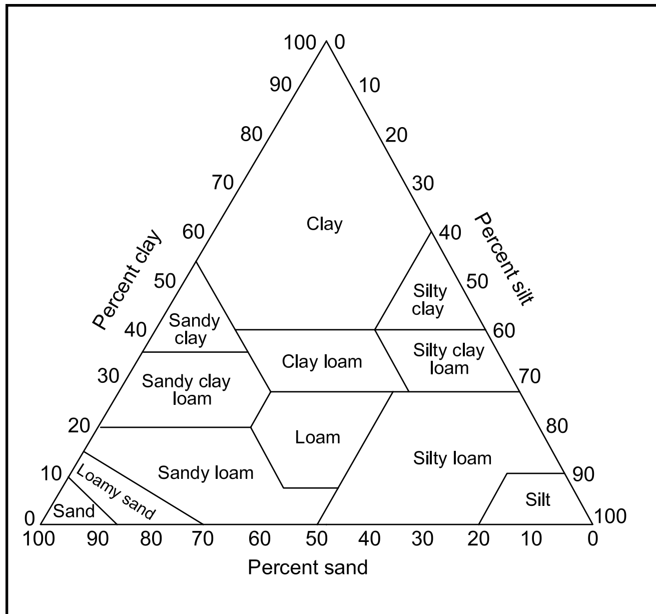


Figure 1–15—This pyramid shows the relationship between soil texture class and a soil's particle-size distribution. To use the diagram, find the percentages of any two of the particle sizes (sand, silt, or clay) on their respective lines. Then project lines inward from these points. Clay should be projected parallel to the sand line, silt parallel to the clay line, and sand parallel to the silt line. The name of the compartment in which the lines intersect is the name of the soil's textural class.

and hold water well but do not become waterlogged. Because they hold water and nutrients well, silty soils are good for plant growth. However, they compact easily and the compacted soils can be erosive if they are dry. Clay soils drain poorly. They are often resistant to erosion. They compact easily when wet, but not when they are dry.

Loamy soils, which contain roughly equal proportions of sand, silt, and clay, often are considered most favorable. They have some of the favorable characteristics of all of those soils. Loamy soils are highly susceptible to compaction. When rock fragments are incorporated into the soil, they reduce the risk of compaction and erosion. If rock fragments are excessive, they provide a poor medium for plant growth. Restorationists should assess the texture of the surface mineral horizon, at least, to help predict the severity of compaction and erosion, as well as the extent to which low soil moisture and fertility are likely to limit plant growth.

Soil structure, the way in which soil particles are arranged, can be altered by disturbance and can become a major limitation to restoration success. Soil structure is the spatial grouping of soil particles into aggregates: clusters of air spaces and soil particles held together as a clod, crumb, block, or prism (Brady and Weil 2002). Larger aggregates—those larger than 0.01 inch (250 micrometers)—allow improved infiltration and drainage, but are easily destroyed by disturbance. The abundance of larger aggregates is highly correlated with mycorrhizal fungal hyphae and fine roots. Small aggregates—those smaller than 0.01 inch (250 micrometers)—are formed from particles of primary minerals, soil organic matter that is being converted to humus, microbial residues, and inorganic oxides. Once formed, these aggregates are much more resistant to disturbance than larger aggregates. Aggregates provide water-holding capacity and allow water and air to diffuse within a soil.

Ideally, soils have 50 percent or more of pore space. Aggregation of soil particles occurs over time as a result of processes such as the synthesis of clay and humus, movement of nutrients, cycles of freezing and thawing, and biotic interactions. Seeds are less likely to be caught and germinate if the soil surface is smooth, a characteristic of soils that have been compacted and lost their structure. Restorationists should compare the structure of the disturbed site to the reference site to assess the severity of compaction problems and the loss of soil aggregates. The need for soil amendments is largely dictated by the severity of structural disturbance.

Soil moisture and its availability to plants is largely determined by soil texture, organic matter, the extent to which the soil has been compacted, and topographic effects on water supply. The topographic effects will be discussed under microclimate. No matter how much moisture soils with sandy textures receive, they will hold relatively little. Soils with silt and clay particles will hold more moisture. Surface organic matter decreases the evaporative loss of water, while organic matter incorporated into the mineral soil will increase the soil's water-holding capacity.

Compaction usually decreases water-holding capacity by reducing water infiltration and porosity. However, in sandy soils, compaction can increase water availability (Blom 1976). The likelihood that drought will limit plant establishment and growth should be assessed. First, consider the general climate of the area (in some places drought is never a problem, while in others, it always is) and local topography (depositional areas and depressions should be less prone to drought than ridges, for example). Then evaluate the influence of soil texture, organic content, and the degree of compaction.

Plants require many different mineral elements that must be obtained from the soil. The availability of these soil nutrients has a profound influence on plant growth. In many wilderness environments (such as those at high elevation or in deserts), nitrogen is the element needed in most abundance and the element most likely to be limiting. Nutrient availability is determined to a great extent by the nature of the parent material and the local climate. However, nutrient availability also is profoundly affected by soil organic matter content and by the activity of soil micro-organisms, characteristics that are readily disturbed at recreation sites. Organic matter is a source of nutrients and its presence helps soil particles hold onto mobile nutrients that would otherwise be leached away by water percolating through the soil.

Soil micro-organisms decompose soil organic matter and release (mineralize) nutrients, making them more readily available to plants. They also promote the aggregation of soil particles. These micro-organisms obtain their energy from organic matter, providing another example of organic matter's importance, and they release hormones, allelochemicals, and chelators into the soil. Allelochemicals are compounds that prevent another organism from growing nearby. For instance, in the Mojave Desert, creosote bush (*Larrea tridentata*) releases an allelopathic chemical into the soil that keeps other plants (including other creosote bushes) from growing nearby. Chelators are compounds that make nutrients more available to plants.

Many micro-organisms, including mycorrhizal fungi and bacteria, develop symbiotic relationships with plants, extending the ability of plants to capture nutrients and water. Ninety percent of all plant species are estimated to form mycorrhizal associations that allow nutrients and water to be interchanged through the root systems of plants connected with fungal hyphae.

Other micro-organisms form crusts on the soil surface. Particularly in arid environments, these crusts are critical both in nutrient cycling and in protecting soils from erosive forces. Larger soil organisms (such as ants and earthworms) help improve soil structure and aeration. These biological concepts and processes are described further in chapter 3.

Generally, soil fertility problems can be dealt with best by increasing the organic content of the soil and promoting development of microbial populations. In areas where the upper soil horizons have been removed, exposing less fertile subsoil, or where unusually rapid plant growth is critical, fertilization may be worthwhile. Infertile soils are a natural characteristic of many mountainous areas and should not be a problem in the long term, if other soil limitations can be corrected.

1.3.1b Plants

Restorationists need to understand how plant growth requirements vary during different stages in the plant's life history and how characteristics of different plants influence their establishment, growth, and reproduction. This knowledge is important when selecting species for planting, selecting planting techniques, and assessing the techniques to maintain plantings. A basic understanding of genetic considerations is important when collecting or producing plant propagules (collecting seed, digging transplants, or propagating plants in a greenhouse).

1.3.1c The Life Stages of a Plant

A vascular plant undergoes a series of stages in its life. Each stage has different requirements. In particular, we need to understand the biology of seeds, seedlings, and mature plants.

For plants to recolonize a disturbed site from seed, seed must be present on the site. Seeds arrive on a site through seed rain and seed dispersal. Seeds produced by a mother plant typically are deposited near the base of the plant or just a short distance away (often less than 3 feet or about 1 meter for herbaceous plants). Dispersal distances increase as plant height increases and seed size decreases. In addition, specialized appendages on seeds can facilitate wind dispersal or dispersal by animals. Seeds also build up in the soil, where they provide a long-lived seed bank.

Often, there is little relation between the abundance of species aboveground and the abundance of seeds in the soil. Colonizing, early successional, and short-lived species are often particularly common in the soil seed bank. Restoration success may not be limited by the availability of plant propagules if the disturbance is small (allowing seeds to disperse to the site from undisturbed areas nearby) or if the seed banks are intact.

To germinate, seeds must find safe sites (figure 1–16), microhabitats that allow seeds to escape hazards (such as predators, competitors, toxic substances, and pathogens) before germination. Safe sites also must provide the conditions to overcome seed dormancy. Seed germination is inhibited until dormancy is broken.

Figure 1–16—The installation of this closure sign created a safe site for plants to become established.

Breaking dormancy can require a specific light intensity, photoperiod, temperature, moisture, fluctuations in conditions, or physical changes, such as abrasion. Overcoming seed dormancy should not be a problem if seeds are sown in the field at the appropriate time under conditions that mimic natural conditions. Dormancy can be a concern when seeds are collected and propagated in greenhouses. Reports and books describe detailed techniques for breaking dormancy (Young and Young 1986, 1992).

Finally, safe sites must provide conditions that allow germination to proceed. The shape and size of seeds, in relation to soil particle size, largely determine:

- Whether a seed will lodge in the soil rather than blow away across the surface
- Whether the contact between the soil and the seed is good, allowing for the optimal flow of water from soil to seed

The lack of safe sites often can be a limiting factor where soils are compacted, soil structure has been lost, there is no organic matter, and no plants provide shelter from wind and sun.

When an area has enough seeds and safe sites, seeds will germinate, and seedlings will emerge and become established. Initially, the seed coat breaks down and a rootlet (radicle) emerges and elongates. The rootlet anchors the seed in the soil and begins to absorb water and solutes (dissolved minerals). Then a shoot (hypocotyl) emerges from the seed, pierces the soil surface, and expands into a photosynthetic surface, allowing the plant to survive independent of seed reserves. Limiting factors during seedling establishment include compacted soils (that roots and shoots cannot penetrate), and desiccation (because of inadequate soil moisture). In some alpine environments, frost activity (aggravated by trampling that denudes soil surfaces) is a major cause of seedling mortality (Roach and Marchand 1984). Plants that emerge from large seeds are better able to survive the initial stresses of seedling establishment because they can rely longer on reserves within the seed.

Once established, seedlings grow into mature plants, reproduce, and eventually die. Growth of mature plants depends largely on the plant's ability to obtain light, water, and nutrients, assuming it is not damaged or killed by grazing animals, trampling, or some other disturbance. During the initial phases of restoration—when plant density is low—competition between plants should not be a concern.

Poor soil structure, low organic matter content, and altered soil microbial populations may contribute to unusually slow growth of the first plant colonists. Plant growth is determined to a great extent by the ability of the root system to grow and capture water and nutrients. Compacted soils can seriously restrict root growth and contribute to soil water stress, while depleted soil organic matter and soil biota can limit the availability of nutrients. After plants have begun growing, competition between plants for resources becomes an additional concern. Inadequate resources can affect the competitive fitness of plants as well as their ability to reproduce.

1.3.1d Plant Characteristics That Influence Restoration

Plants vary greatly in morphology (their forms and structures) and in their reproductive biology. Certain characteristics make plants easy to establish and grow, while other characteristics make planting difficult. The planting and maintenance techniques required vary depending on these characteristics.

Higher plants can be divided roughly into those with woody shoots (trees and shrubs) and those with herbaceous shoots (forbs and graminoids). Woody structures are resistant to damage, but recover slowly (Cole 1995b). They also grow relatively slowly. Woody plants may be easier to grow from transplants than from seed. However, woody plants often have lower root:shoot ratios than herbaceous plants (Bliss 1985), making them more susceptible to damage during transplanting.

Rooting patterns have a pronounced influence on how well a plant is adapted to different soil conditions as well as on the ease of transplanting. Plants with high root:shoot ratios can extract more water and nutrients from the soil (per unit of leaf area) than plants with lower ratios. If a disturbed site has low moisture or nutrient levels, species with high root:shoot ratios are more likely to be successful. Plants with fibrous root systems are more likely to flourish as transplants than plants with spreading root systems (May and others 1982). Plants with taproots often do not transplant well because it is so difficult to avoid damaging the taproot.

Plants and environments vary in the relative importance of sexual reproduction (from seed) and clonal growth (in which plants spread primarily through growth and asexual reproduction by rhizomes, stolons, or tillers). Sexual reproduction is likely to be less important than clonal growth in environments or species where plant productivity is limited (because fewer resources are available to produce reproductive structures) or where the frequency and predictability of favorable conditions for germination are low. Clonal growth is especially important in high-altitude and in arid environments.

Plants also vary greatly in the extent to which they allocate energy to reproduction. Some plants tend to be short lived, mature rapidly, and devote most of their energy to producing flowers, fruits, and seeds. Although the terminology is not entirely equivalent, these plants may be described as *r-selected*, *ruderal*, or *early seral*. These plants tend to have smaller seeds that are readily dispersed, higher growth rates, and higher nutrient demands. They commonly colonize disturbed areas (figure 1–17).

Figure 1–17—Partridgefoot (*Leutkea pectinata*), an early-seral species of the subalpine zone, forms dense mats of foliage topped by creamy clusters of tiny flowers. The tiny seed, flanked by paper-thin membranous margins, is dispersed by wind.

Other plants are long lived, slow growing, and allocate much less energy to reproduction. These are K-selected, stress-tolerant, or late-seral species. These plants are abundant only in successionally advanced communities.

1.3.1e Genetic Considerations

The general reason for paying attention to genetics is to maintain contemporary patterns of biodiversity within and among populations of plants. One of the most important components of biodiversity is genetic diversity. Most species have a number of different ecotypes, populations that are genetically adapted to different habitats. High-elevation ecotypes of a species, for example, grow better at high elevations and low-elevation ecotypes of the same species grow better at low elevations. Besides elevation, plants develop ecotypic responses to such environmental variables as light intensity, soil chemistry, growing season, and moisture availability.

In restoration, this ecotypic diversity is critical for at least two reasons. First, since ecotypes are best adapted to particular environments, it only makes sense to plant them in the conditions where they will grow well. Second, this genetic diversity should be considered as wealth that has built up over the years, as species have adapted to environmental conditions. Genetic mixing of different ecotypes diminishes this wealth, making all populations respond less favorably to environmental conditions.

Ecotypic variation can be maintained by collecting seed or transplants from similar environments that are as close as possible to the site to be restored. Rules of thumb include collecting seed or transplants within the same major vegetation type (preferably within the same watershed) and not transferring material more than 500 feet (about 152 meters) in elevation. Sources should be even more localized when species are self-pollinated and in areas with steep topography or discontinuous ecological and physical characteristics.

It is also important to maintain genetic variation among individual plants within the same population. Doing so may not affect the short-term success of your restoration project, but it is important to the long-term fitness of the plants. This genetic variation allows the population to adapt to highly localized conditions or to changes in conditions over time. This genetic variation is maintained by collecting seed or transplants from a large and diverse set of plants, located in scattered populations, while equalizing contributions from each plant.

Some common rules of thumb include collecting from a minimum of 30 donor plants located at least 100 feet (about 30 meters) apart. While it is common to suggest that seed and transplants should be from healthy plants, one should refrain from selecting only the largest and most vigorous plants. Collecting from plants of varying size and vigor will contribute to genetic variation. If conditions change, the less vigorous plant may be better suited than the plant that is vigorous under current conditions. Chapter 3 includes additional guidelines that will help you think about applying these principles to your projects.

1.3.1f Microclimate

It is important to consider microclimate throughout a restoration project, but it is particularly important to do so during the critical stage of seedling establishment. The seedling is vulnerable as it switches from relying on the reserves within the seed to external sources of nutrients. Generally, the most favorable microenvironments provide shelter from wind, some shade from excessive sunlight, and funnel moisture to the plant. Restoration projects are likely to be less challenging in areas where moisture is less limiting (such as in depressions or below a late-melting snowbank) and where there are some rocks, downed logs, or trees to protect seedlings from wind and excessive sun (figures 1–18a, 18b, and 18c).

To some extent, microclimates can be created. Plantings can be shaded, for example. In the desert, it is common practice to create pits in the soil. These pits collect moisture and organic matter and protect plants from wind.

Figures 1–18a, 18b, and 18c—Late-melting snow and partial shade contributed to the recovery of this campsite at Snow Lake in the Alpine Lakes Wilderness, WA. When the site was first treated by transplanting wildling plugs in 1980, it was extremely compacted and completely devoid of vegetation (top). Thirteen years later, dense native vegetation covers the site (middle) and is even spreading into an adjacent social trail. By 1998, shrubs began to invade the site (bottom), showing that the site is becoming more like the reference condition.

1.3.1g Animals

When a restoration project is being designed, animals need to be considered. Insects, birds, and small mammals will consume seed that is scattered on the ground. Seeding density can be increased or a mulch can be added on the ground surface. Larger mammals will consume seedlings and mature plants. Plants grown in the greenhouse and fertilized plants can be attractive to herbivores. This is a particular problem in arid environments, where it is often necessary to protect plantings with screening.

1.3.2 Ecosystem Processes

Restoration will be more likely to succeed if it works with rather than against the processes that operate in natural environments. Working with natural processes requires understanding how those processes operate, how disturbances have disrupted them, and how the processes can be repaired. This section focuses on hydrological processes, succession, and biotic interactions. Energy flow and nutrient cycling, two of the most fundamental ecosystem processes, are considered under the topic of biotic interactions.

1.3.2a Hydrologic Processes

Typically, the hydrologic cycle involves precipitation, incorporation of water into the soil, use and transpiration of some of the water by plants, and transport of excess groundwater by drainage channels to sinks (playas, lakes) or oceans, where water is reincorporated into the atmosphere as it evaporates. The aspect of this cycle that is critical to the restorationist is incorporation of water into the soil. If water runs across the soil, instead of infiltrating, it causes erosion. Surface runoff increases with disturbance, either because topography has been altered, vegetation has been disturbed, or because soils have been degraded.

Problems are most severe in areas where a trail (or road) collects water, concentrating the erosional forces of running water. A partial solution is to place frequent drainage devices or checkdams along the trail. Water continues to be collected by the trail, but it is shunted off the trail before it can do much damage. Erosion is reduced, but is still greater than would occur otherwise. Some of the soil that is eroded is deposited behind the checkdams. A complete solution to the problem would require importing soil to bring the trail back up to grade, so it no longer collects water.

At recreation areas, such as campsites and vista points, excessive runoff is usually a result of soil and vegetation disturbance rather than topographic change. Elimination of vegetation, organic horizons, and rocks, along with compaction of mineral soils, all contribute to reduced infiltration rates and increased runoff. If these sites are small and flat, erosion is generally not a critical problem. However, if sites are large and sloping, erosion can be a problem (figure 1–19). Even on small, flat sites, poor infiltration can contribute to soil water stress and to the loss of seeds as they are washed across the soil surface. On such sites, soil structure needs to be restored and organic matter and mulch layers need to be replenished.

Figure 1–19—The disturbed area of this campsite acts like a funnel, directing the flow of water and silt into Snow Lake in the Alpine Lakes Wilderness, WA.

1.3.2b Succession

Succession is the change in plant species that occurs over time. A disturbed or denuded land surface becomes covered with plants, which are replaced by other plants. Succession will occur on a disturbed site without any human intervention. Restoration is an attempt to increase the rate of succession or to alter the trajectory of succession toward an outcome that closely mimics natural outcomes. This concept is discussed in more detail in chapter 3.

Problems arise when attempts to increase the rate of succession actually slow succession or alter the trajectory of succession and, perhaps, the ultimate state of the ecosystem. Both of these effects have been demonstrated. For example, fertilization may increase the growth of pioneering plant species but retard the development of microbial communities (DePuit and Redente 1988). The result is a more rapid development of vegetation cover, but a slower return to plant communities similar to those that existed before disturbance.

There is considerable controversy among ecologists about how succession proceeds and what drives succession. Early views of succession described a process of successive discrete plant communities, in which the initial colonizers (early-seral species) modify the site so that subsequent invaders (late-seral species) are at a competitive advantage. The late-seral species should outcompete and replace the earlier seral species and, in turn, modify the environment before being replaced by climax species. This model (termed relay floristics) differs from the alternative—the initial floristic composition model.

According to the initial floristic composition model, most species—early-seral, late-seral, and climax species—are on the site initially. Early-seral species germinate in abundance, are initially at a competitive advantage, and dominate the site during early succession; later successional species grow more slowly and do not dominate until much later.

Both models probably contain useful insights, with their validity varying among environments and with the type and severity of disturbance. According to the initial floristic composition model, we should attempt to get propagules of late-seral species onto the site early in the restoration process, along with the propagules of early-seral species. If we do not, late-seral species may never have an opportunity to invade the site. This approach is probably the most useful and conservative approach at most locations.

On sites where disturbance has been severe, late-seral species may not be able to establish and survive. This is probably the case on sites where upper soil layers have been lost to erosion. In these cases, it may be necessary to confine plantings to early-seral species that hold soil, contribute organic matter, and retain or fix nutrients. For instance, nitrogen fixers, particularly legumes, could be planted to build up depleted soil nitrogen (figures 1–20a and 20b).

Figure 1–20a—Bacteria in root nodules allow some nitrogen-fixing plant species, such as bitterbrush (*Purshia tridentata*), to convert atmospheric nitrogen to a soluble form that can be used by plants.

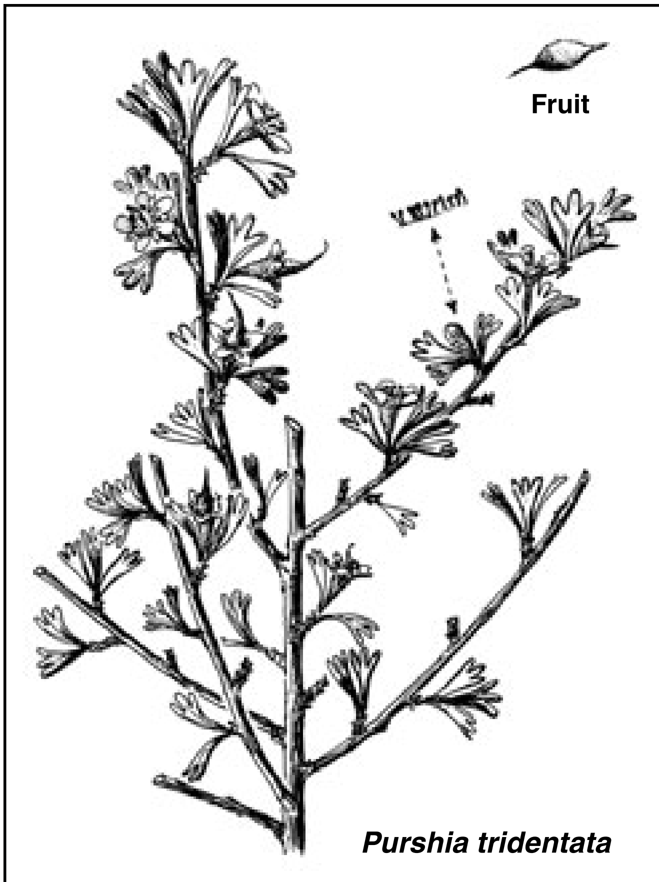


Figure 1–20b—Bitterbrush drawing courtesy of University of Washington Press (Hitchcock and Cronquist 1976).

1.3.2c Biotic Interactions

A number of biotic interactions are of concern to restorationists. We have already discussed herbivory, a potentially serious problem. Animals also can provide benefits. Many animals dig up the soil, breaking up compacted soils and improving the quality of seedbeds. Generally, the interactions between plants and other plants and between plants and soils are of more concern to restorationists than the interactions between plants and animals.

1.3.2d Plant-Plant Interactions

Early in the restoration process, when plant density is low, plant-plant interactions are more likely to be positive than negative. One plant can provide shade for another or protect it from grazing animals. In compacted soils, sometimes the force of several emerging seedlings is needed for any of them to break through the surface. In other cases, one plant species may support mycorrhizal fungi that benefit survival of another plant species.

Negative interactions also are possible. One plant may produce metabolic byproducts (allelochemicals) that inhibit other organisms. As plant density increases, opportunities for negative interactions—through competition for resources—increase. Potential competitive relations will determine the appropriateness of different species mixes we might choose for seeding or planting. Unfortunately, our understanding of competitive relationships among plant species is negligible. This suggests again that the most conservative approach is to try to plant a mixture of species that is similar to the mixture on the site before disturbance.

1.3.2e Plant-Soil Interactions

Interactions between plants and soil micro-organisms are of critical importance to restorationists. Again, our understanding is rudimentary. We know that soil micro-organisms are critical to nutrient cycling and to increasing the efficiency of water and nutrient uptake. We also know that micro-organisms derive their resources from organic matter and exudates from plants. They cannot flourish under certain soil conditions. A site that has been trampled and denuded for many years cannot support a healthy soil biota, because it does not support a healthy plant population. Conversely, it cannot support a healthy plant population because the soil biota is impoverished.

How can this vicious cycle be broken? Again, we have little to go on besides intuition and some common sense suggestions. Soil structure needs to be improved and organic matter needs to be increased. Scarification and organic amendments should help. Perry and Amaranthus (1990) suggest reintroducing micro-organisms at the same time that plants are reintroduced. For field transplants, this can be accomplished simply by transferring small amounts of soil from around donor locations to the restoration site. When seeding or planting greenhouse plants, soil can be dug from nearby areas with similar vegetation and environments. Alternatively, plants can be inoculated in the greenhouse.

1.4 Concluding Thoughts

It is relatively easy to describe ecosystem characteristics and processes, but it is difficult to predict the effects of ecosystem manipulations (which is what our restoration activities are). The systems we are attempting to restore are extremely complex. The effects of our manipulations may not be obvious for decades or centuries. We have invested little in documenting the success of ecosystem manipulations. While many millions have been spent studying how to restore strip mines, for instance, virtually nothing has been spent to study wilderness restoration. Moreover, even when we do know what happened when a particular restoration technique was used, we seldom know why it had the effect it did. Nor do we know if the same thing would happen under other circumstances.

Do we know enough to restore wilderness ecosystems or would we be better off leaving them alone? Each of us would answer this question differently. The severity and potential irreversibility of certain disturbances suggest we may have to pursue riskier policies than some would prefer. However, our inability to predict accurately the long-term effects of our manipulations suggests that we should be more passive than others might prefer. We must balance courage with humility, taking action, but doing so in a manner that is appropriate to the wilderness context.

Chapter 2

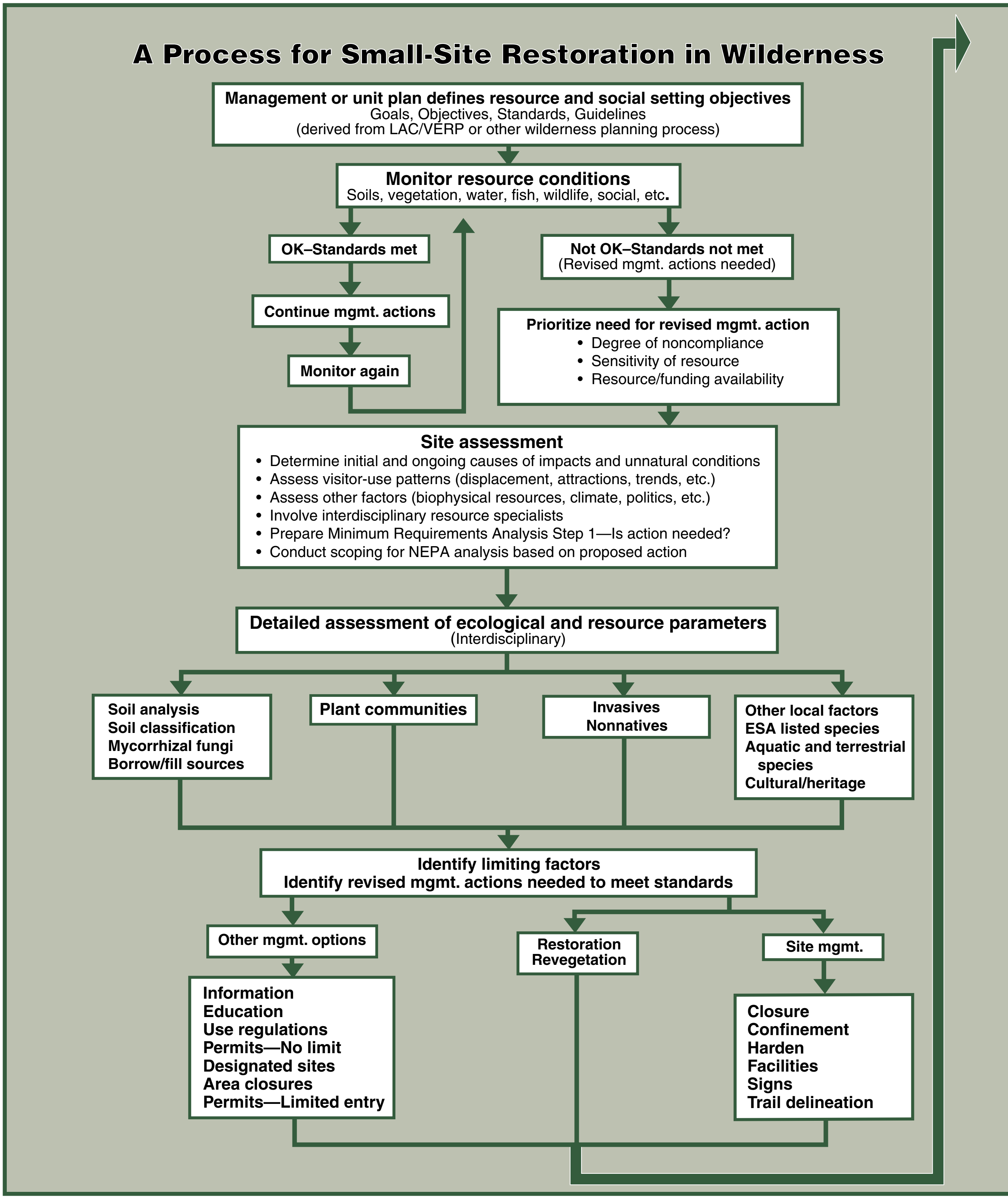
Planning for Restoration of Small Sites in Wilderness

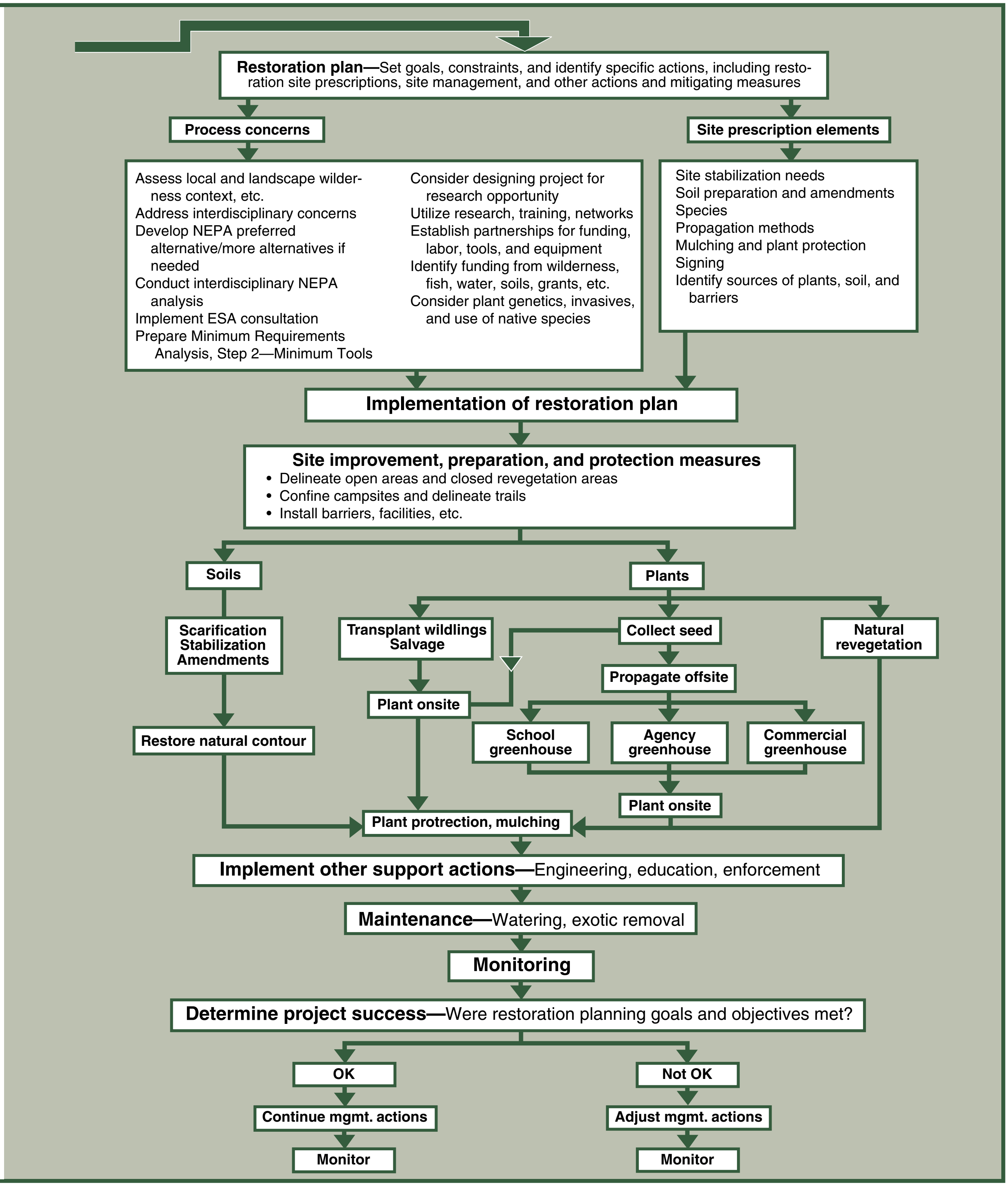
This chapter provides a conceptual overview of the components of restoration planning (figure 2–1) for a wilderness setting with ongoing recreational use. This chapter explains the concepts depicted on the accompanying flowchart, *A Process for Small-Site Restoration in Wilderness*. Chapter 3, which is more technical, will provide the restoration methodologies. This chapter serves more as the "trail map" to help you see where you are headed. Chapter 3 serves as a guide to help you get there.

Just as there is usually more than one right way to travel to a destination, the process laid out in this chapter may not occur in exactly the same order in all restoration projects. That's the wilderness restoration experience!

The flowchart on pages 32 and 33, developed by Tom Carlson of the Arthur Carhart National Wilderness Training Center and others, was revised by Lisa Therrell.

Figure 2–1—Restoration planning in the Desolation Wilderness, CA, considered the Three Es: engineering the project design to succeed, education of the public so they know how to reduce wilderness impacts, and enforcement of regulations designed to protect the wilderness resource.


A Process for Small-Site Restoration in Wilderness
Management or unit plan defines resource and social setting objectives
Goals, Objectives, Standards, Guidelines
(derived from LAC/VERP or other wilderness planning process)
Monitor resource conditions
Soils, vegetation, water, fish, wildlife, social, etc.
OK–Standards met
Continue mgmt. actions
Monitor again
Not OK–Standards not met
(Revised mgmt. actions needed)
Prioritize need for revised mgmt. action
• Degree of noncompliance
• Sensitivity of resource
• Resource/funding availability
Site assessment
• Determine initial and ongoing causes of impacts and unnatural conditions
• Assess visitor-use patterns (displacement, attractions, trends, etc.)
• Assess other factors (biophysical resources, climate, politics, etc.)
• Involve interdisciplinary resource specialists
• Prepare Minimum Requirements Analysis Step 1—Is action needed?
• Conduct scoping for NEPA analysis based on proposed action
Detailed assessment of ecological and resource parameters
(Interdisciplinary)
Soil analysis
Soil classification
Mycorrhizal fungi
Borrow/fill sources
Plant communities
Invasives
Nonnatives
Other local factors
ESA listed species
Aquatic and terrestrial species
Cultural/heritage
Identify limiting factors
Identify revised mgmt. actions needed to meet standards
Other mgmt. options
Information
Education
Use regulations
Permits—No limit
Designated sites
Area closures
Permits—Limited entry
Restoration
Revegetation
Site mgmt.
Closure
Confinement
Harden
Facilities
Signs
Trail delineation


Restoration plan—Set goals, constraints, and identify specific actions, including restoration site prescriptions, site management, and other actions and mitigating measures
Process concerns
Site prescription elements
Assess local and landscape wilderness context, etc.
Address interdisciplinary concerns
Develop NEPA preferred alternative/more alternatives if needed
Conduct interdisciplinary NEPA analysis
Implement ESA consultation
Prepare Minimum Requirements Analysis, Step 2—Minimum Tools
Consider designing project for research opportunity
Utilize research, training, networks
Establish partnerships for funding, labor, tools, and equipment
Identify funding from wilderness, fish, water, soils, grants, etc.
Consider plant genetics, invasives, and use of native species
Site stabilization needs
Soil preparation and amendments
Species
Propagation methods
Mulching and plant protection
Signing
Identify sources of plants, soil, and barriers
Implementation of restoration plan
Site improvement, preparation, and protection measures
• Delineate open areas and closed revegetation areas
• Confine campsites and delineate trails
• Install barriers, facilities, etc.
Soils
Plants
Scarification
Stabilization
Amendments
Transplant wildlings
Salvage
Collect seed
Natural revegetation
Propagate offsite
Plant onsite
Restore natural contour
School greenhouse
Agency greenhouse
Commercial greenhouse
Plant onsite
Plant protection, mulching
Implement other support actions—Engineering, education, enforcement
Maintenance—Watering, exotic removal
Monitoring
Determine project success—Were restoration planning goals and objectives met?
OK
Not OK
Continue mgmt. actions
Adjust mgmt. actions
Monitor
Monitor

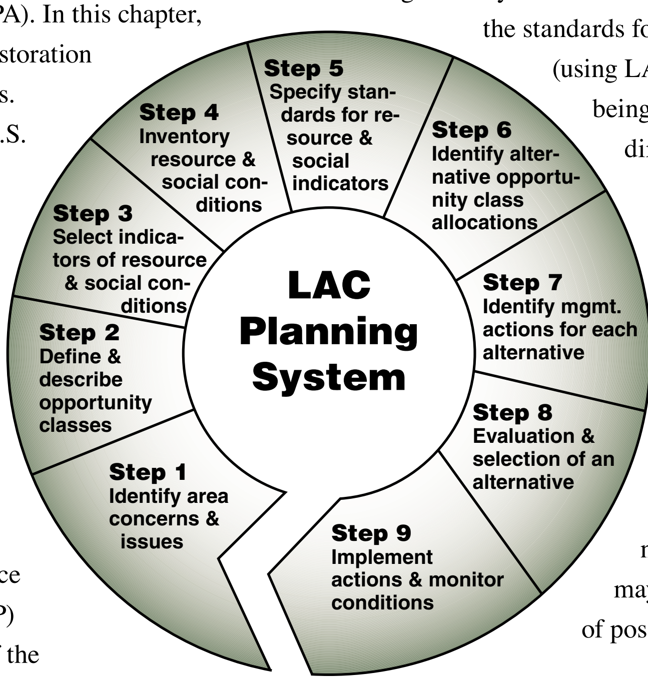
2.1 Gathering the Information To Formulate a Plan

As can be seen from the flowchart, *A Process for Small-Site Restoration in Wilderness*, many factors must be considered during the restoration planning. Law, policy, and land management plans provide sideboards and the desired conditions for the land. A site assessment examines the role of historical and continuing influences, leading to proposed management actions. Designing a holistic package of management actions helps support restoration success.

2.1.1 Using Your Land Management Plan and NEPA

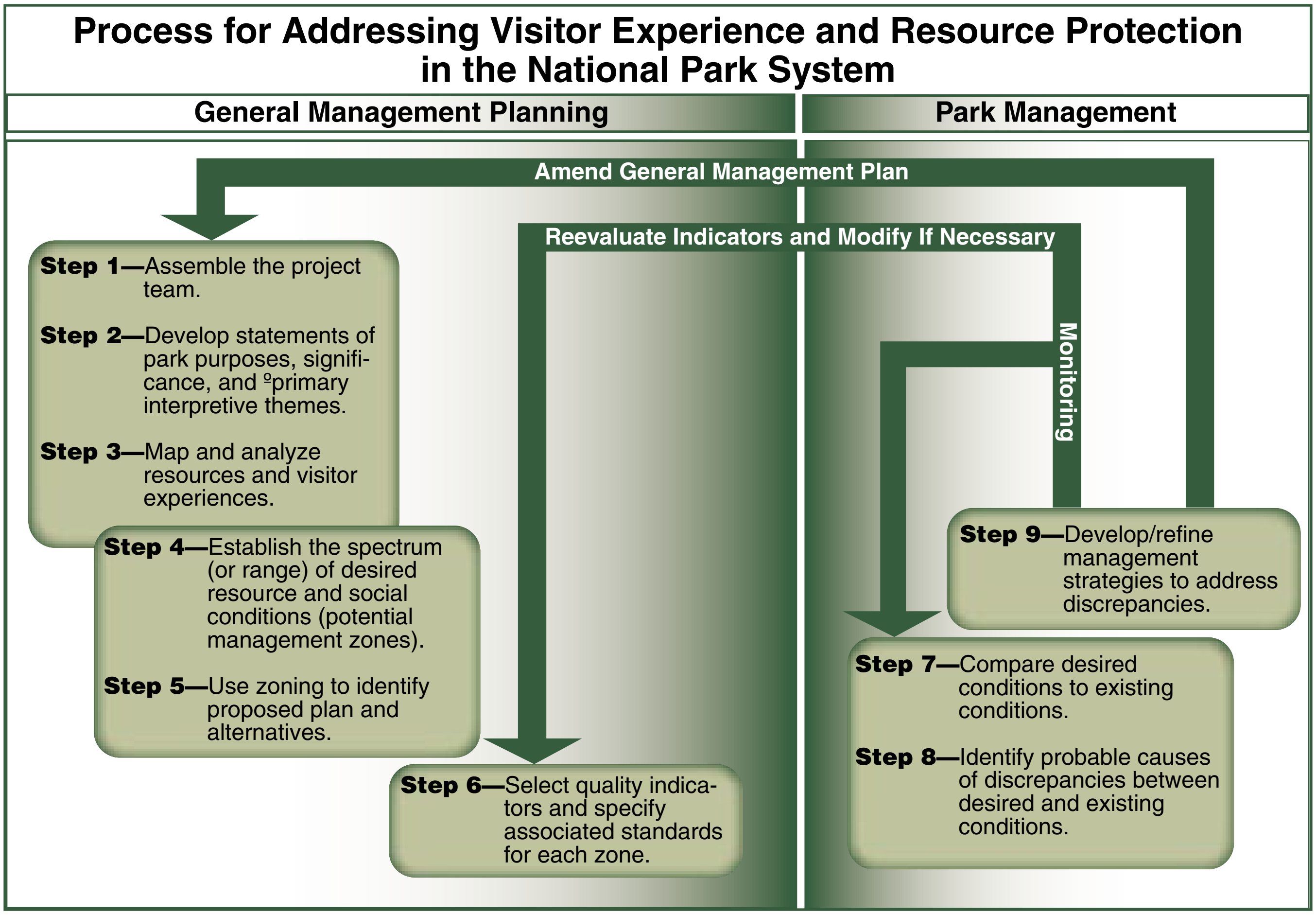
Most agencies manage wilderness and backcountry areas according to management direction provided in a land management plan. The management plan, tiered to law and policy, provides clear goals, objectives, and management standards that steer wilderness management. Development of a restoration project, as with any project on Federal land, also needs to follow the procedures mandated by the National Environmental Policy Act (NEPA). In this chapter, we will show how to dovetail restoration planning with the NEPA process.

Many Forest Service and U.S. Department of the Interior Bureau of Land Management (BLM) wildernesses use the accompanying Limits of Acceptable Change (LAC) model (Stankey and others 1985) to formulate management direction. The U.S. Department of the Interior National Park Service uses the accompanying Visitor Experience and Resource Protection (VERP) framework (U.S. Department of the Interior National Park Service 1993) for planning. Both planning systems include the concept of zones governed by indicators of condition. Management actions are selected to achieve desirable resource conditions, while preserving an appropriate social setting.



Resource conditions are monitored to determine when management actions might be needed. Restoration treatments often are considered because recreation-related campsite condition indicators such as vegetation loss, campsite density, or a site's distance from a trail or water do not comply with the management plan. Other campsite condition indicators may be based on social concerns, such as whether campers in one site can see and hear campers in another site (such sites are said to be intervisible and interaudible). These indicators are likely to have quantitatively measurable standards. Qualitative standards also may come into play, such as indicators describing the degree of naturalness or those describing the overall visual setting. Indicators based on other resources may drive the need for action. For example, such indicators might be based on riparian condition, unique plant communities, or soil degradation.

Once monitoring for an area has been completed, managers analyze whether conditions in the area comply with the standards for that zone or opportunity class (using LAC terminology). If standards are being met, current management direction may be appropriate; restoration doesn't need to be considered (See the flowchart, *A Process for Small-Site Restoration in Wilderness*, at the beginning of this chapter.). If conditions in the area do not comply with management standards, revised management actions are needed. Vegetative restoration may, or may not, be part of the mix of possible solutions.



2.1.2 Using the Minimum Requirements Decision Process

If a proposed project is in congressionally designated wilderness, the first step is to ask the question—"Is administrative action needed?" This question is the first step in the Minimum Requirements Decision process, developed to ensure compliance with the intent of the Wilderness Act and agency policies. The *Minimum Requirements Decision Guide* is available from the Arthur Carhart National Wilderness Training Center (Arthur Carhart National Wilderness Training Center 2004) and on the Internet at *http://www.wilderness.net*. Worksheets in the guide will lead you through the minimum requirements decision process.

To oversimplify the minimum requirements concept, administrative action in wilderness is "required" when necessary to achieve the purposes of the Wilderness Act, such as:

- Allowing for natural processes, solitude, and primitive and unconfined recreation
- Ensuring a lack of human manipulation and permanent structures
- Providing for provisional uses of wilderness, such as valid existing rights
- Addressing emergencies

2.1.3 Planning Scale and Priorities

Planning scale also needs to be determined. Many of the national parks have developed programmatic vegetation restoration management plans covering the entire park. The Rocky Mountain National Park *Vegetation Restoration Management Plan*, version 2, 2006, is one example. This approach allows managers to look at all human-caused disturbances, define parkwide goals and objectives, and sort out priorities and procedures at a large scale. Individual projects are selected based on priorities. Selected projects receive site-specific planning.

It doesn't make much sense to go through the entire planning process for one campsite. On the other hand, if the plan includes too large an area, such as an entire watershed, the site-specific planning required for a successful plan (and required by NEPA) might become unmanageable.

One suggestion is to focus on one destination or trail, or on closely interrelated areas. For example, planning might be more efficient if you consider restoration of nearby campsites when planning a trail relocation and restoration project. A number of wilderness projects have employed this strategy quite successfully. The planning area should be large enough (figure 2–2) to address the problems created when users are displaced to other areas nearby.

Determining which projects receive priority depends on resource management objectives, conditions in the planning area, budgets, and compatible opportunities. It would be easy to say that the most serious problem should be your first priority. But there may be too many constraints to solve the most serious problem right away. The constraints may be financial, biological, logistical, financial, or political. For your first projects, consider choosing ones where your chances of success are fairly high. Another approach would be to choose projects that address small pieces of a complex problem. As you learn from your successes, you can move on to more challenging projects.

Figure 2–2—The planning scale should be large enough to address problems that arise when users are being displaced from closed areas.

2.1.4 Forming an Interdisciplinary Team

Persons knowledgeable about any resources potentially affected by a proposed project need to be included on an interdisciplinary team. At a minimum, a typical Forest Service team would include the recreation or wilderness manager, an archeologist or cultural resource technician, a botanist, and a soil scientist (figure 2–3). Additional support may be needed from a landscape architect, wildlife biologist, fisheries biologist, hydrologist, engineer, or trails specialist. The team will identify and gather any additional resource data or visitor-use data needed.

Figure 2–3—An interdisciplinary team field trip will help build a mutual understanding of human-caused impacts and viable solutions.

The next chapter will provide technical background to help you evaluate erosion, soil, and vegetative conditions as part of your site assessment. The remainder of this chapter will help you identify and correct problems caused by human use, so your plan can address not just the problems, but their causes.

Figure 2–4—Restorationists Joy Juelson and Greg Shannon collaborate on a site assessment for Juelson's research project in the Alpine Lakes Wilderness, WA.

2.1.5 Developing a Site Assessment

The next step is to develop a more detailed assessment of the planning area. The purpose of the site assessment (figure 2–4) is to gather the information for a clear problem statement and site-specific proposed action. A quick initial assessment may be followed by a more exhaustive assessment. During the site assessment process, you will gather all the information needed to formulate the preferred alternative (NEPA terminology) and write a detailed restoration plan. The restoration plan also will include other supporting management actions.

2.1.6 Assessing Historical Human Influences

The team will determine the initial and ongoing causes of resource impacts. Don't assume that the impacts you see today are from current recreation use patterns—take enough time to research past uses of the area that may have contributed to current conditions. Even if a specific use ended long ago, you will want to understand the full context of impacts caused by human use. This research also will help identify cultural sites you may not wish to disturb with a restoration project.

Historical influences might include grazing, old sheep camps, use by large groups, old developments such as roads or mines, logging (yes, even in wilderness), homesteads, administrative sites, airfields, or damage by off-road vehicles. In some cases, an area may continue to erode or noxious weeds may continue to spread, even after the original cause of the problem has been eliminated.

Your staff archeologist may help you find relevant information sources. You may wish to consult agency heritage resource files, range records, local historical libraries, local history books or memoirs, and expedition journals. Local residents, oldtimers at your work unit, and former employees also are excellent sources of information.

2.1.7 Assessing Current Human Influences

Impacts may be declining because of changes in use. Perhaps conditions have stabilized to a new norm. Thorough observation and analysis of current human use patterns is

A Lesson Learned the Hard Way

One week, I hiked to Lake Mary in Washington's Alpine Lakes Wilderness, joining the restoration crew to plant a site we had designed as an experiment to test the effectiveness of inoculating planting holes with mycorrhizal fungi (figure 2–5). Working together, we were planting specific numbers of several species in a grid pattern, mixing a spoonful of inoculum into half the planting holes. While we were planting the site with greenhouse-grown stock, I was surprised to feel a very sharp angular chip of stone that was not characteristic of the powdery ash-based soil. Taking a close look, I recognized the tiny chip as a lithic flake—a byproduct of making arrowheads. A thoughtful debate on whether to stop or continue our work followed. Because the site had already been disturbed with a restoration treatment 10 years before, we continued our work. This taught me the importance of making sure an archeologist or cultural resource technician visits each site before treatment.

Lisa Therrell

Figure 2–5—Inoculating planting holes with mycorrhizal fungi.

essential. The restorationist or wilderness manager needs to be part psychologist or sociologist, gaining a feel for the management tactics that might succeed or fail based on an understanding of the local clientele. Future management actions will be based, in part, on these determinations.

Identify the regulations that are in place. How are these regulations helping your situation? How might they be making things worse? Are additional regulations or adjustments needed?

Look for situations where management direction or regulations do not complement the indicators or standards, resulting in noncompliance. For example, the Alpine Lakes Wilderness in Washington has a campsite vegetation loss standard of 400 square feet (about 37 square meters) or less. The group size limit, including stock, is 12. Groups of 12, especially those with stock, occupy and impact larger areas than allowed by the standards. In fact, any group with a large wall tent will impact more vegetation than allowed by the 400-square-foot (about 37-square-meter) standard. Such discrepancies need to be addressed during the planning process.

It is helpful to think of the larger project as a series of miniprojects. Assign each campsite and trail segment (or other feature) a unique number, cross-referenced to a map (figure 2–6). The number allows each feature to be tracked all the way through planning, implementation, and monitoring. The project area map needs to be detailed enough that each campsite and trail segment can be identified on the ground. Be sure to indicate key features such as north, the

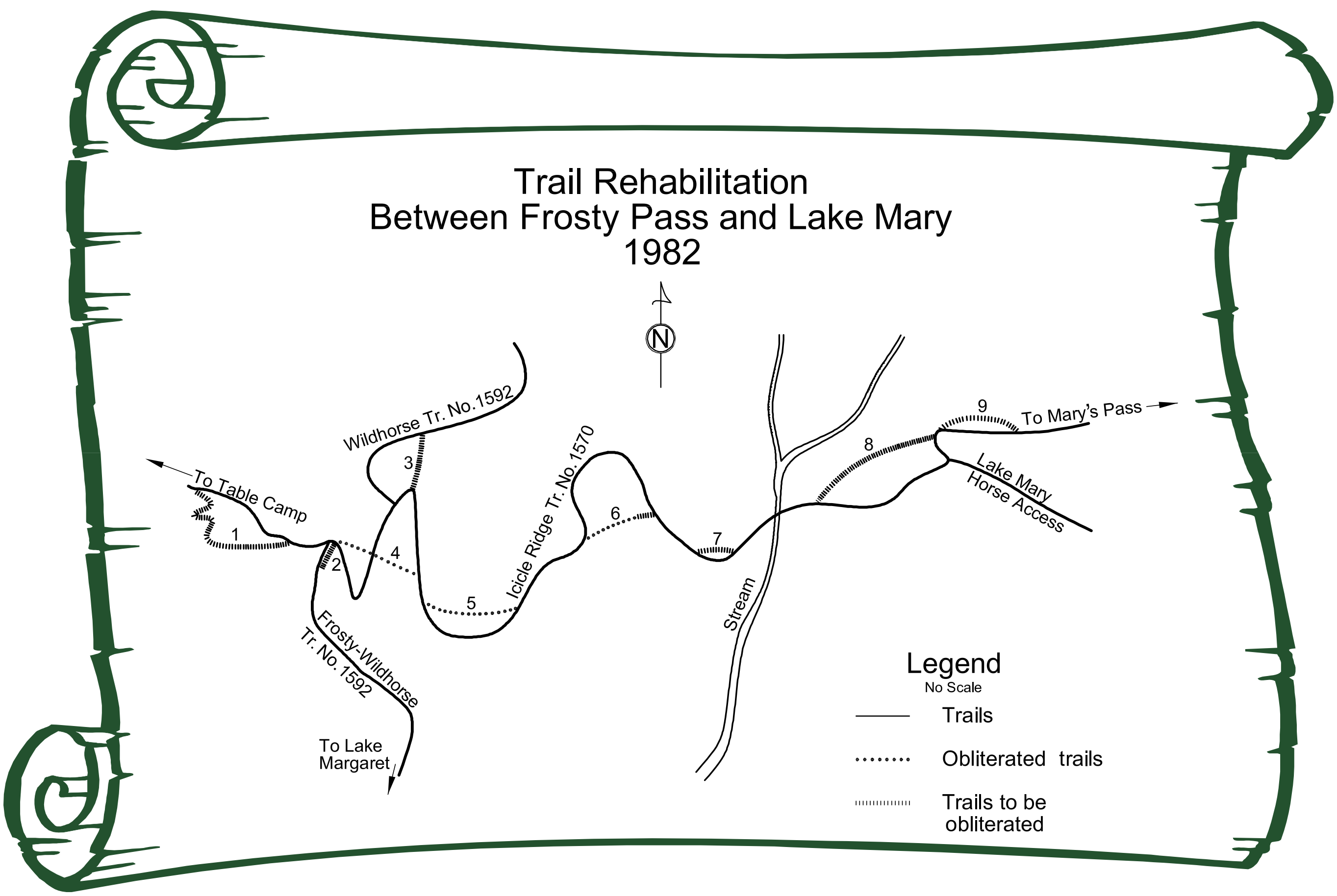


Figure 2–6—One example of a project map.

direction of waterflow, system trails, the direction to system trails, and so forth. It may not be possible to map every single social trail at this scale; more detailed site maps will show the trails. Establish photopoints, so you can use a series of pictures of impacted campsites and trails to show changes in their condition. Your numbering system will allow you to identify each site.

It pays to study human use patterns in an area. Hang out and watch what people do during peak-use periods and during different parts of the use season.

- Who are the users?
- Where do users wander when they select a campsite?
- Which campsites receive the most use?
- Are all campsites occupied during peak-use periods?
- Does campsite occupancy change use patterns (forcing visitors to bypass the occupied sites when accessing areas of interest, for example)?
- Do groups avoid camping in campsites that have impacts?
- How and where do users access water, firewood, and toilet areas?
- How do fishing and other area attractions affect trail and campsite development?
- What other seasonal conditions influence use patterns? High water? Seasonal snowmelt?

Evaluating Snowmelt Patterns

For any wilderness with winter snow cover, the early-season snowmelt is a pivotal time for assessing impacts. When the ground is partially covered with snow, visitors will select campsites and travel routes differently than when the ground is bare. They may walk or camp on vegetation because they can't find the main trail and camps, forming duplicate sites and trails (figures 2–7a and 7b). Restorationists will want to avoid closing the first trails and camps that become snowfree. Document your findings with photos and maps.

Figure 2–7a—Would you believe that the Pacific Crest Trail could still be covered with snow on Labor Day weekend?

Figure 2–7b—Two additional trails were formed to skirt the snow. This problem can be avoided with careful planning, but you have to survey conditions in the early season when the snow is beginning to melt off trails and camps.

Presence or lack of shade during the hot months? Access to water?
- How do current regulations and other management strategies shape these patterns?

Review use statistics for the area. Are use levels stable, rising, or falling? Have the types of users changed over time?

What behaviors, use levels, or conditions need to change to bring the planning area back into compliance with standards or management objectives?

Each specialist will contribute to the assessment based on his or her discipline. Chapter 3 discusses a process and method for completing a soil and vegetation assessment. Assuming that restoration might be part of a proposed action, the focus is on comparing the damaged sites to one or more reference sites to determine what is missing and what can realistically be restored.

The information gathered for the site assessment is quite specific. Plant species and the distribution of native plant communities are noted. Potential site treatments are based on soils, vegetation, and use patterns. An archeologist or cultural resource technician needs to survey any sites that might be slated for ground disturbance or another action that might affect heritage resources. Native sources of plant material, rock, and quantities of nearby fill are noted.

In short, any factors that could limit project success are identified. Appendix A, *Treatments To Manage Factors Limiting Restoration*, lists potential factors that limit restoration success, along with the corresponding treatments.

2.1.8 Problem Statements

It is helpful to write a problem statement to focus planning. This brief statement includes the location of the project, description of the impacts addressed by the project, causes of the impacts, the magnitude of the impacts, and any special considerations. A sample problem statement would be:

The project area is on the south shore of Cradle Lake (figure 2–8), between Trail No. 1550 and the lake. It involves two campsites, totaling about 4,000 square feet (about 372 square meters), six social trails, and an area where horses are tied for short periods. These sites are now the best options for camping with stock at Cradle Lake, even though they are inside the 200-foot (about 61-meter) setback where camping is not allowed. Cradle Lake also has a 200-foot (about 61-meter) campfire setback from the lakeshore. Illegal fires and stock camping continue to be a problem. Campsite sizes do not conform to standards. The campsites and social trails, highly visible from most portions of the lake basin, are not in conformance with visual standards.

Figure 2–8—Cradle Lake in the Alpine Lakes Wilderness, WA.

2.1.9 Scoping the Proposed Action

Fairly early in the interdisciplinary process, the team will formulate a proposed action (NEPA terminology) describing the purpose for the proposed project, the project location, and the types of actions that might be taken. At this point, the proposed action is specific to a particular area, but doesn't go into excruciating detail. For example, enumerate exactly which campsites will be closed for restoration. The proposed action is included in a letter and mailed to the concerned public as a part of scoping for the NEPA process. Scoping is the stage when concerns about the proposed action and possible mitigating measures are identified.

Based on the Cradle Lake example, a proposed action might look like this:

The proposed action includes the following strategies:

- **Relocate Trail No. 1550 to a more durable location through talus on the other side of the lake.**
- **Retain the portion of the old system trail needed to provide lakeshore access.**
- **Restore the portion of the old system trail where it leaves the lake to climb toward the pass.**
- **Close and restore the two large lakeshore campsites.**
- **Direct users to camp on benches away from the lake and at a nearby stock camp.**
- **Close four of six social trails.**
- **Harden the two remaining social trails to provide durable lakeshore access.**

Your agency may have a standard scoping mailing list. Work with your team to identify other interested parties, such as local user groups, wilderness advocates, native plant societies, or outfitters and guides. Your scoping process also may include public meetings, club meetings, field trips, articles for newsletters, or press releases. You may need to contact representatives of the U.S. Fish and Wildlife Service or the National Marine Fisheries Service. They are expected to consult on the project if threatened or endangered species or their habitats could be affected.

2.1.10 Selecting Management Actions To Meet Standards

During this stage of planning, your team will identify the appropriate management actions needed to help the planning area meet wilderness standards or other applicable standards. Even though we often start a planning process with restoration in mind, don't assume that restoration is the answer. Other options may be more desirable or appropriate. The process of selecting the best management actions begins with studying the range of options, then choosing options that best complement each other to form an appropriate holistic solution. Even though it is tempting to rush ahead to plan a restoration project, back up a few steps to ensure that you have considered all options.

You have already determined that administrative action is necessary, the first step of the *Minimum Requirements Decision Guide* (Arthur Carhart National Wilderness Training Center 2004). The next step is to determine the minimum tool. This step requires answering four questions.

- What are the alternative methods for solving the problem?
- What are the effects and benefits of each method?
- What is the minimum tool and the rationale for its selection?
- What operating requirements will minimize impacts?

This section will discuss the first three questions.

2.1.11 The Minimum Tool

Sometimes the concepts of "primitive tool" and "minimum tool" are confused. Part of the tradition of wilderness management includes using primitive tools. Essentially, primitive tools are the tools used during the settlement of America. Based on the language of the Wilderness Act, primitive tools don't have motors and don't have wheels (even though the wheel itself is primitive). Our expert use of these tools and techniques preserves a disappearing slice of our heritage, representing one of the enduring cultural and historical benefits of wilderness.

On the other hand, the minimum tool may not be primitive. The minimum tool represents the minimum action necessary, within the context of wilderness values, to meet management direction or to accomplish other administratively necessary activities. The minimum tool may refer to tools, such as a type of saw, drill, or transportation. Or it may refer to actions, such as the degree of signing, regulation, or physical development in wilderness.

At this stage, consider all the available options. Some methods may not appear to be feasible initially, but conduct some research before reaching conclusions.

Management direction and policy will help frame the options that are appropriate. Many wilderness areas are zoned into "opportunity classes" using the LAC process. The types of management actions identified as acceptable in a transition or semiprimitive zone might be considered unacceptable or possibly a last resort in a primitive or pristine zone. For example, obvious barriers and signs to delineate trails and campsites may be appropriate in the transition zone, but those techniques are inappropriate in a pristine zone.

Public support also will shape the selection of management options. In one study of high-use wilderness destinations, visitors showed low support for limiting use and high support for intensive campsite management techniques, including active restoration (Cole and others 1997). A similar study, using an exit survey of persons who had visited heavily impacted wilderness locations, found that 71 percent did not view agency management favorably. When visitors were surveyed after visits to areas with restoration work in progress, 74 percent reported "positive" to "extremely positive" views of management (Flood and McAvoy 2000).

Before beginning a restoration project, contact users or groups that might be displaced by change (figure 2–9). They may suggest a better alternative that addresses public desires and wilderness protection. In the Seven Lakes Basin of the Selway Bitterroot Wilderness, ID, local stock users suggested a number of ideas that allowed continued limited stock use of fragile subalpine lake basins (Walker 2002).

Figure 2–9—"I love this place—We do, too."

These publications will help guide your wilderness impact analysis:

- *Minimum Requirements Decision Guide* (Arthur Carhart National Wilderness Training Center 2004)
- *Managing Wilderness Recreation Use: Common Problems and Potential Solutions* (Cole and others 1987)
- *The Limits of Acceptable Change (LAC) System for Wilderness Planning* (Stankey and others 1985)

2.1.12 Types of Management Actions

The challenge facing wilderness managers is to develop methods of handling problems that not only address the symptoms, but solve the underlying problems. We will need public support for our new tactics. To borrow vernacular from off-highway vehicle managers, we need to address "The Three Es"—engineering, education, and enforcement. We engineer the project's design so it will succeed, we educate to persuade visitors to practice new behaviors, and we enforce regulations when visitors don't comply.

Wilderness research scientist David Cole (Cole and others 1997) suggests three broad categories of management actions for reducing recreation impacts:

- Reducing recreational use
- Changing visitor behavior with information and education
- Managing sites intensively by controlling recreational use patterns and restoring damaged sites

Each category of actions has strengths and limitations. Your proposed actions are likely to include a mix of these categories of action as you craft a viable management solution.

2.1.12a Reducing Recreational Use

While limiting use is commonly accepted in the national parks, it is generally seen as a draconian measure in national forests. Limiting use may be the only way to stabilize or reverse impacts to soil and vegetation, especially in areas with too few campsites to support the existing overnight use. Limiting use is not only politically unpopular, it could exclude some users from wilderness and may displace users to other areas. The displaced users could increase the environmental and social impacts at those areas.

The large volume of literature on permit systems should be reviewed carefully before considering limits on use. Nonetheless, it is always appropriate to ask whether the level of use is contributing to the problem. If resource impacts cannot be stabilized at current use levels, reducing use becomes a minimum tool.

An indirect method of reducing use is to lengthen the approach to an area—usually by closing a road to lengthen trail access. Many wilderness visitors will oppose the mere suggestion of lengthening access. However, this management action may complement other objectives, such as reducing road mileage for wildlife habitat needs or reducing the costs of road maintenance.

2.1.12b Changing Visitor Behavior With Information and Education

The strategic use of information and education can, over time, change unnecessary or discretionary high-impact behaviors, such as littering or damaging trees. However, intensified educational programs are unlikely to reverse damage to vegetation and ongoing soil erosion. It is difficult for many visitors to grasp the impact of their individual actions. Changes to old ways, such as the tradition of enjoying a campfire, evolve ever so slowly.

If stabilizing or reversing damage to vegetation and soils is a project goal, education can be an important tool, but education alone will not solve the problem. Visitors need to be told the actions they can take to prevent further damage, such as staying in the confines of existing campsites and trails, learning to travel off trail on durable surfaces (rock, snow, or gravel), refraining from having a fire, and not removing any vegetation.

Common methods to convey information include Web sites, brochures, information on maps, trailhead posters, signs at the site, contacts by receptionists, and contacts by wilderness rangers (figure 2–10). If adequate resources are available, a more comprehensive wilderness education program may be designed. A process for wilderness education planning is available at *http://www.wilderness.net.*

Principles of Leave No Trace Wilderness Travel

- Plan ahead and prepare.
- Travel and camp on durable surfaces.
- Dispose of waste properly.
- Leave what you find.
- Minimize campfire impacts.
- Respect wildlife.
- Be considerate of other visitors.

(For more information, visit *http://www.lnt.org*)

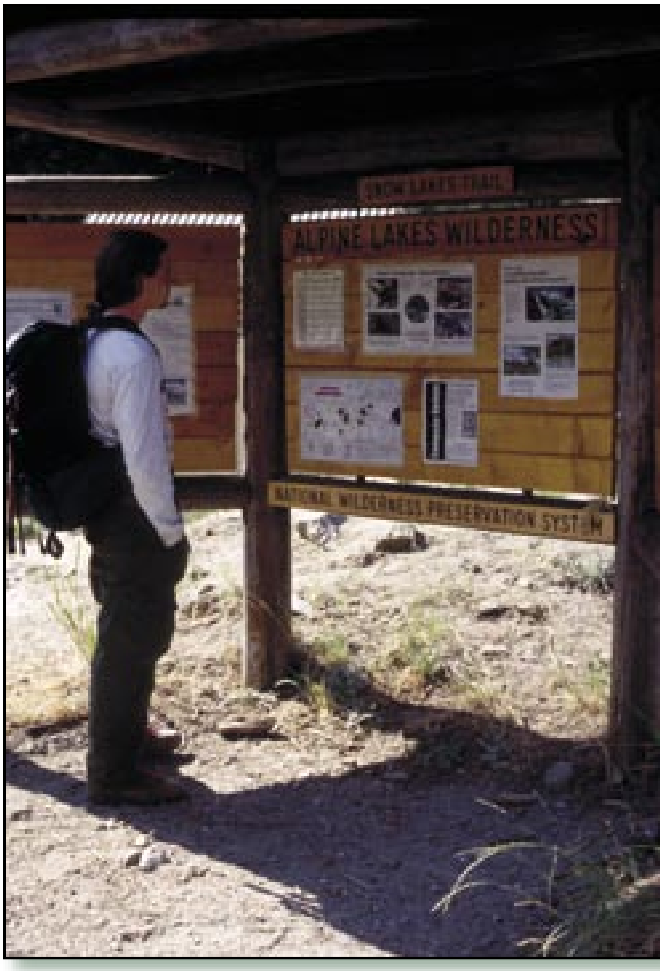


Figure 2–10—Information on bulletin boards can help visitors learn what's expected of them in wilderness. Photos or maps help draw visitors in for a closer look at the materials.

2.1.12c Intensive Site Management

Intensive site management includes a variety of direct controls: using regulations to require visitors to practice low-impact techniques for wilderness travel, redesigning the area to stabilize impacts and concentrate use, and actively restoring damaged soil and vegetation. The techniques discussed for each of these controls will focus primarily on correcting damage to soil and vegetation. Other problems identified through monitoring and the site assessment process may require additional solutions.

2.1.12d Regulations and Enforcement

Chances are that some regulations may already be in place to reduce impacts to soil and vegetation. Perhaps these regulations have worked in part, but have not allowed the area to reach the appropriate objective for management. It may be necessary to alter regulations or put additional regulations into place. Regulations mandate low-impact behavior in situations where visitors may not normally choose such practices. Regulations are unlikely to succeed without enforcement (figure 2–11).

Figure 2–11—Regulations enforced by rangers can help reduce damage caused by visitors in wilderness areas. Regulations might apply to the entire wilderness, to a series of wilderness areas, or to specific locations.

When considering new regulations or changes to existing regulations, consider the potential that users and their impacts could be displaced. Would this displacement be acceptable? If displaced users meet their needs close by, the impacts will show up close to your project area. They might camp in the next basin over. Perhaps they will seek similar destinations elsewhere or choose another favorite place. Some visitors will seek out completely different wilderness areas, perhaps in other States, where they are less regulated. Visitors displaced from the Enchantment permit area of the Alpine Lakes Wilderness in Washington said they would adopt all strategies discussed above, making it difficult to pinpoint a specific effect of displacement (Shelby and others, no date).

2.1.12e Regulations To Reduce Use Directly

Any regulation may result in an indirect decrease in use if the user would rather go elsewhere than endure the regulation. However, some regulations may reduce overall use directly without actually limiting the number of groups that enter the area. Examples include:

- **Limiting Group Size**—A group size limit (for people and/or stock) can be set based on levels that are sustainable for the campsites, stock-holding areas, and available forage. Larger groups have more impact, especially when their activities spread onto vegetated areas and their social interactions require lots of travel back and forth. Some areas of a wilderness may require a lower group size than other areas. Regulations limiting group size can be very effective if they are combined with low-impact practices. Large groups will be displaced to areas of wilderness that allow larger groups or to other backcountry areas.
- **Limiting Length of Stay**—Many national forests already limit the length of stay (2 weeks is quite common). At a popular destination, a shorter length of stay may prevent crowding while giving more persons an opportunity to visit.
- **Prohibiting Certain Uses in an Area**—An area may be closed to a certain type of use, such as all stock use, overnight use with stock, or any overnight use altogether.
- **Modifying the Location of Use**—Some possibilities include requiring the use of designated campsites, prohibiting use at closed sites, or having a camping setback from a lake or desert waterhole.

It is important to have a clear understanding of why a site should be closed. Is it to allow access to a day-use area? To improve the view for others? To reduce campsite intervisibility? To prevent further damage?

Closing a site may or may not fix a problem. Sites are unlikely to recover on their own unless they are impacted only lightly or are located in the lushest of environments. Malcontents may remove signs in closed sites and then say, "We didn't see a sign."

Designated sites help concentrate impacts (figure 2–12). Designated stock camps and areas to hold stock are an excellent way to concentrate stock impacts.

There is less incentive for campers to remove a sign that designates a campsite, because once the sign is gone they can no longer camp there. Any area that charges a fee for entry incurs more liability for environmental hazards, such as falling trees. If a campsite is designated, forcing a visitor to use it, liability issues may become an increased concern.

Figure 2–12—Signs telling campers where they're welcome to camp aren't as likely to be pulled up and thrown into the bushes as signs telling campers where not to camp.

Camping setbacks should be considered only when adequate and appropriate places exist to camp outside the setback. Tragically, the number of impacted sites doubled at many wilderness lakes after setbacks were instituted. These sites heal slowly, even with active restoration. Setbacks are common and ecologically important in desert areas where wildlife need undisturbed access to limited water.

Stock setbacks can be used to protect fragile areas, such as shorelines. The national forests in the Washington Cascades implemented a 200-foot (about 61-meter) setback from all lakes and ponds; stock can be within this area only if they are being led to water or passing by on a trail. This practice also reduces user conflicts.

2.1.12f Regulations To Reduce High-Impact Behaviors

Examples of regulations that can be used to reduce or eliminate high-impact behaviors include:

- **Prohibiting Campfires**—Combined with limiting group size, prohibiting campfires may be the most important regulation to reduce impacts to vegetation and soils. Campfires thoroughly alter soil qualities, making revegetation very difficult. Even in areas where a firepit is considered an acceptable impact, firewood gathering creates many additional impacts. Users create social trails while they are scavenging for wood. The loss of woody debris eliminates habitat for a host of organisms and an important component of the forest floor that contributes to soil development. Trees are damaged as firewood gatherers snap off limbs, creating a human browse line. Large feeder logs in a campfire often remain partially burned. Unless firewood is locally abundant and excess social trails are not a problem, prohibiting campfires (figure 2–13) is a good practice that will reduce impacts over the long term.
- **Requiring Low-Impact Methods for Confining Stock**—Many low-impact alternatives for confining stock eliminate the need to tie stock to trees (except for short periods). Tying stock to trees not only destroys vegetation around the tree, but could expose the tree's roots and girdle the bark, possibly killing the tree. The telltale sign that a tree has met this fate is a doughnut-shaped depression with a standing dead tree or stump in the middle. Appropriate use of highlines, hobbles, pickets, or electric corrals can prevent this problem. Regulations requiring these types of stock containment are in place at several wilderness areas, including the Lake Chelan-Sawtooth Wilderness and Alpine Lakes Wilderness in Washington.

Figure 2–13—Campfires may leave scars that are difficult to erase.

- **Limiting Campsite Occupancy**—Some areas, such as the Mt. Hood Wilderness, regulate the number of tents or people allowed for a given campsite. This practice prevents a large group from spilling onto vegetated areas. Nor can a small group claim a large campsite that is better suited for a large group. Displacement to other nearby camping areas could become an issue as groups seek a site for a party of their size.
- **Prohibiting Cutting Switchbacks or Leaving the Trail**—Switchback cutting leads to contin-

ued erosion and loss of leaf litter and limbs that often are used to disguise switchback cuts. A special order can be written to make it illegal to cut switchbacks. Rangers in some areas with fragile soils or vegetation, such as Paradise Meadows at Mt. Rainier National Park, cite visitors who leave the trail. With many thousands of visitors, this is the only way to stabilize human-caused impacts to the meadow.

- **Modifying Timing of Use**—Several methods can be used to regulate timing of use without instituting a permit system. The first method is to prohibit certain uses (such as overnight use or grazing) when the potential for impact is the highest. This may be early in the season, when vegetation is just emerging, or it may be at another time to accommodate seasonal wildlife habitat needs. A fee could be charged during the sensitive time period to discourage use. Another way to discourage use could be to gate a road and prohibit vehicle access during the sensitive time period.
- **Redesigning Infrastructure To Stabilize Impacts and Concentrate Use**—With the possible exception of constructed trails or administrative sites, most impacts at wilderness destinations are caused by the ordinary wear and tear of public use. User trails, often called social trails, generally connect various amenities that visitors are seeking. Such amenities might include campsites, viewpoints, access to water for drinking or fishing, firewood sources, and private places for toileting.

Such a network of trails often looks like the spokes of a wheel, or a spider's web. Users often establish many more trails than are really needed (figure 2–14). Trails shift, depending on snow conditions, wet areas, rockfall, or fallen logs. In addition, trails often shift onto vulnerable locations, such as along the fall line of the slope, which is subject to erosion, or onto areas with fragile vegetation.

Figure 2–14—Multiple trails established by visitors can cause more damage than one carefully located trail. A maze of trails going every which way is a common problem in recreation areas.

Most campsites are on relatively flat areas near water. The earliest users (in some cases, indigenous peoples) wanted the best view, which means that many scenic areas have large, denuded, and sometimes eroding campsites. When these sites are occupied, other users may have difficulties reaching the shoreline or campsites nearby.

Good project planning will take into account a variety of criteria that might include:

- Leaving the necessary infrastructure of social trails and improving them if needed
- Closing unneeded social trails
- Closing excess campsites, while leaving enough campsites to meet demand
- Stabilizing or closing eroding trails or campsites
- Closing or reducing the size of trails or campsites that do not meet visual objectives
- Closing campsites that are visible from other campsites
- Closing trails or campsites to protect other resource values, such as cultural artifacts, rare plants, or animal habitat
- Installing barriers to delineate trails and campsites
- Hardening trails or campsites as needed to concentrate use

- Providing facilities to concentrate use (figure 2–15), such as toilets or facilities to hold stock.
- Identifying signs that might be needed to inform the public
- Anticipating the likelihood of public acceptance and the range of possible user behaviors when making these determinations

Methods for implementing these criteria will be discussed in more detail in chapter 3.

Figure 2–15—The Wallowa toilet design has been used by the Forest Service since the 1920s. A carefully located toilet helps alleviate recreation impact by reducing the number of social trails, by reducing vegetation disturbance, and by protecting water quality.

2.1.13 Passive Restoration of Damaged Soil and Vegetation

Before concluding that a vegetative restoration treatment is the minimum tool, consider whether natural recovery, or passive restoration, might be successful. Passive restoration allows secondary succession of native plant communities once the conditions preventing vegetative recovery have been abated. Passive restoration has the benefit of allowing Mother Nature to do the healing, producing a more natural result.

Sometimes active restoration may not be necessary once the human impact has been removed. This is especially true in areas:

- That are wet
- That still have live plant material in the soil
- Where the soil is in good condition to serve as a seedbed
- That have a suitable native seed source nearby

The following criteria favoring passive restoration are based on those used by Rocky Mountain National Park (U.S. Department of the Interior National Park Service, Rocky Mountain National Park, 2006):

- The disturbed site will resemble an early-, mid-, or late-seral condition for an undisturbed community growing under similar environmental conditions.
- Adequate native propagules remain in the soil or plants will be able to colonize from nearby sources.
- The disturbed site will preserve natural interactions between individual plants growing on the site and adjacent to the site, including their genetic integrity.
- No exotic plant species that could impede revegetation are on the disturbed site or nearby.
- The site is more than 160 feet (about 50 meters) from a trail, destination area, or campsite.
- Recreation use can be controlled to manage site recovery.
- The site's appearance is not a factor.
- The site has topsoil, natural levels of soil compaction, and soil microbes are still intact.
- The site is stable (no active human-caused soil erosion).
- No other factors are known that might impede natural recovery.

Passive restoration requires managers to accept whatever time scale Mother Nature dictates. For example, the lush forests of the Eastern United States seem to recover rapidly without human intervention. In contrast, most upland Western ecosystems require decades, if not centuries or millennia, to recover. A long timeframe for recovery may be acceptable—give yourself permission to think beyond human time scales. Such long time scales may not be acceptable if resource values would continue to degrade or if social setting objectives cannot be met. Appendix D, *Case Studies*, includes an excellent case study that describes how implemention of a grazing system allowed a meadow on the Dixie National Forest in southern Utah to recover naturally.

Natural Recovery in Rocky Mountain National Park

At Rocky Mountain National Park, a lake shoreline (figure 2–16a) recovered naturally (figure 2–16b) after a dam was breached. The soil was rich with nutrients and still held a large seedbank and pieces of live plant material. The park was able to save the expense of a costly restoration project (Connor 2002).

Rocky Mountain National Park addresses passive restoration in the park's vegetation restoration management plan (U.S. Department of the Interior National Park Service, Rocky Mountain National Park, 2006). A go/no-go checklist (U.S. Department of the Interior National Park Service 2002) ensures that passive restoration is considered when criteria can be met. Otherwise, the checklist helps managers document the need for active restoration.

Figure 2–16a—A lakeshore in Rocky Mountain National Park, CO, before recovery.

Figure 2–16b—The same lakeshore after natural recovery.

2.1.14 Active Restoration of Damaged Soil and Vegetation

Even with volunteer labor and partnerships, restoration projects in wilderness are expensive per square foot of area treated. In addition, restoration is a form of manipulation, although at a very small scale. For example, future researchers will want to know where your restoration sites are so they don't become confused while studying otherwise intact native plant communities.

Restoration becomes the "minimum tool" when less manipulative options would fail to return the area to an acceptable standard. If excessive impacts remain once other options have been implemented, restoration may be part of the solution.

2.1.15 Adjusting Management Actions: A Tale of Two Lake Basins

The examples of two different lake basins in the Alpine Lakes Wilderness in Washington show how management can be adjusted to bring areas toward their desired condition. The "minimum tool" strategy for each of these locations, developed through trial and error, involved a multipronged approach.

Lake Mary (figure 2–17), a subalpine lake basin, experienced many years of sheep grazing before it became a popular recreation destination. In the 1960s, managers installed picnic tables, a hitch rack, and garbage pits. In the 1980s, a number of management strategies were employed to reduce impacts. These included:

- Prohibiting campfires
- Installing two toilets
- Moving the access trail to a more durable alignment
- Restoring the area by transplanting plants salvaged during the trails project

By then, the area had become wilderness, so all structures other than toilets were removed. Additional wilderness-wide regulations included a limit of 12 combined people and stock in a group, a 200-foot (about 61-meter) setback for stock access, and a regulation making it illegal to enter a closed restoration site.

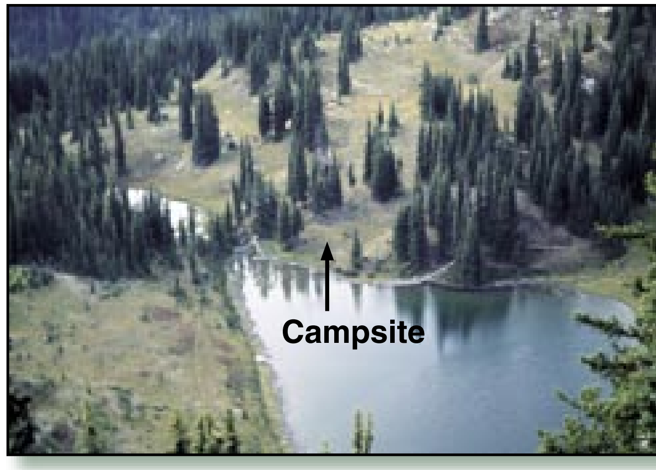


Figure 2–17—Lake Mary, a popular recreation destination in the Alpine Lakes Wilderness, WA.

These strategies were working in part, but the impacted areas, including the areas that had received restoration treatments, were not improving (figure 2–18), according to monitoring data. Factors that prevented the impacted areas from improving included continued erosion and compaction,

Figure 2–18— The worst eyesore at Lake Mary was a large, denuded stock camp near the lake's outlet. Despite previous restoration attempts, continued use of the site deterred recovery. (This view of the camp was created by splicing two photos.)

continued human and stock use in closed sites, and the loss of the organic soil horizons. In 1992, a site assessment was completed. The following year, additional strategies were adopted. They included:

- 200-foot (about 61-meter) stock setback
- Campsite designations to concentrate use
- Delineation of trails and campsites with barriers such as logs or rocks

The restoration work was redone with a much more intensive approach—steep sites were stabilized with check-dams before being backfilled with mineral soil and topsoil carefully gleaned from sources nearby. High school students grew plants from locally collected seed. In addition, the sites were seeded when the seedlings were transplanted. A better erosion-control product was used and oak signs were installed to close restoration sites permanently. At first, a small map was installed to help users locate campsites, because only two sites were visible from the lakeshore.

Fast forward from 1993 to 2002. The revised management strategy is meeting with success. The restoration work is flourishing in most locations. Visitors know where they can walk and camp. The foreground view by the lake is dominated by native vegetation and well-located trails (figure 2–19), instead of a huge, bare-dirt campsite that blocked access to the lake. Visitors say that Lake Mary looks far better now than it did in previous decades.

Now let's contrast the experience at Lake Mary with the experience at the popular Enchantment Lakes Basin. In comparison to the annual precipitation of 81 to 100 inches (2.06 to 2.54 meters) at Lake Mary, the Enchantments receive about 46 to 60 inches (1.17 to 1.53 meters) of precipitation, mostly as snow in winter. Climbing into the Enchantments requires a very steep scramble. As a result, the area has never had stock use or commercial grazing. The area became popular in the 1960s and 70s when hundreds of people camped in the 3-square-mile (7.8-square-kilometer) basin on weekends. Campsites formed on virtually every flat, dry spot. Hundreds of campsite inventories document extensive impacts during that era.

Figure 2–19—Two volunteers and a paid crewleader spent 33 workdays installing barriers and adding locally collected topsoil to this former stock camp at Lake Mary. Native greenhouse-grown seedlings were planted, and locally collected seed was sown across the site. Four years later, most plantings were thriving and seeded species, such as Sitka valerian, were becoming established. Barrier logs defining the trail remained in place. Silt no longer flowed directly into the lake, and a more attractive view greeted visitors to Lake Mary.

By the early 1980s, the vegetative condition had declined to a range rating of "poor" because of human foot traffic alone, despite many aggressive management strategies. Campfires had been prohibited, toilets had been installed, trails had been hardened, and group size had been limited. Local soils are so thin and dry that attempts at restoration succeeded only in the wettest of locations (figure 2–20). Because the lakes had measurable levels of fecal coliform

Figure 2–20—Thin, dry soils in the Enchantment Lakes Basin have scuttled most restoration efforts. (This photograph was digitally altered to remove distracting elements.)

and fecal streptococcus from human and dog feces, vault toilets were installed and dogs were prohibited.

In 1987, a limited entry permit system was implemented to manage a carrying capacity of no more than 60 people overnight at one time. A few years later, the group size was reduced to eight. Education messages (figure 2–21a) were strengthened to coach people on how to walk, camp, and even urinate (the mountain goats paw up vegetation to eat the salt in urine) in a way that protects fragile meadows.

Figure 2–21a—Coauthor Chris Ryan (left) checks a climber's limited entry permit and explains policies designed to reduce visitor impacts at the fragile Enchantment Lakes Basin.

Long-time visitors are beginning to notice an improvement in vegetative condition, which can be attributed to many factors. Trail hardening (figure 2–21b) and cairns marking the trails keep most traffic on a durable route, preventing hikers from creating parallel trails and damaging sensitive shorelines. Well-established campsites can accommodate the reduced use. Prohibiting campfires and providing toilets (figure 2–21c) further limited the development of social trails. This area will always pose management challenges, but the overall trend of wilderness quality is no longer declining. Because of the area's harsh conditions, management actions other than restoration proved more effective in reaching objectives.

Figures 2–21b and 21c—The combination of reducing use, hardening trails (top), installing toilets (bottom), and prohibiting fires has been a more successful strategy than restoration for reducing impacts at the Enchantment Lakes Basin.

2.2 Putting It All Together—Developing a Restoration Plan

Now that your team has considered all the options, it's time to develop a strategy likely to succeed at meeting wilderness goals and standards. In other words, your team determines the minimum tool based on step 2 of the *Minimum Requirements Decision Guide*. If you are completing an environmental assessment to comply with NEPA procedures, you will develop several alternatives (such as a no action alternative, a partial alternative, and a complete restoration alternative)—with each alternative being responsive in some way to the key issues identified during scoping.

The restoration plan includes pertinent wilderness goals from the land management plan or regulatory mandates and incorporates local concerns. The plan describes all the supporting actions to be taken as part of a holistic solution. These actions may include reducing use, furthering information and education programs, or recommending intensive site management techniques. An example of a good restoration plan is included in appendix D, *Case Studies*.

A restoration plan contains site-specific prescriptions for miniprojects that are linked to sites and trails numbered on a map (see figure 2–6). A specific prescription is developed for each miniproject, including the objective of the treatment, stabilization and site preparation treatments, soil treatments, vegetative treatments, and plant protection treatments. The needs for signs also are identified.

A project area map should show the location of specific action items, such as which trails and campsites are to be closed and which are to remain open. Sketch maps help show the design of each miniproject. For instance, a sketch map might show how a campsite could be reconfigured. Photos of each miniproject site (figure 2–22) can be included with the prescription and sketch map. Provide enough detail that a new crewleader could implement the prescription successfully.

Locations of suitable native materials, such as rocks and downed logs, are mentioned in the plan. Note potential sources of local fill material, topsoil, and organic matter. Strategies for rehabilitating borrow areas are addressed.

Figure 2–22—If a site is discontinuous, identify each of the sections to be treated. For example, the area above the trail could be identified as site F–1 and the area below the trail as site F–2.

The restoration plan also addresses the best management practices for protecting wilderness resource concerns. Examples of best management practices include:

- Measures for preventing the introduction of noxious weeds, pests, or diseases
- Protocols for maintaining the genetic integrity and diversity of plant communities when collecting plant materials for the project

Select the best management practices that are responsive to the minimum tool requirement, answering the question, "What operating requirements will minimize impacts?"

Safety concerns also should be engineered into the project. What tools, supplies, personal protective equipment, and work procedures will reduce exposure to illness or accidents? How will the crew communicate if a problem occurs? Consider the logistics of an evacuation, should one be needed. Develop or revise a safety plan and job hazard analysis. Job hazards specific to restoration work include back strain (figure 2–23), knee strain, wrist fatigue, injuries related to walking, and dirt that can get into your eyes. Exposure to environmental factors becomes more prolonged because the work keeps you in one place. Consider the effects of sun, heat, cold, precipitation, and biting insects.

The restoration plan may include cost estimates and potential labor sources. For logistical planning, it is helpful to include specific information, such as the length and width of each miniproject, and estimates of any materials needed; the numbers of checkdams and their sizes, the amount of fill material needed, the estimated number of plants needed (by species), the amount of erosion-control blanket needed, and the number of signs that might be needed. Such detailed estimates will take much of the guesswork out of purchasing supplies, growing plants, and determining whether adequate native materials are available at the project location.

Figure 2–23—Lift with your legs, not with your back! Plan restoration projects with safety in mind.

It is helpful to identify in advance where workers will camp (figure 2–24a), and any supplies they will need. If workers will stay at the area for days or weeks, determine how to arrange for food storage, water treatment and storage, and warm clothing and bedding. Careful planning will prevent further damage to vegetation. It is also important to identify a staging area where tools, supplies, and plant materials can be stored (figure 2–24b). If transplants remain

Figures 2–24a and 24b—Select camping (top) and staging (bottom) areas that can absorb the wear and tear of crew traffic.

in containers for more than a couple of days, they will need to be watered. If the staging area is not near water, you may need to provide water with a gravity feed system, or use another system to provide water.

The restoration plan may consider a phased-in approach, treating the less stable or more highly visible problems first. This is especially important when the project is not fully funded, or when all the work cannot be completed at once.

The restoration plan should include an information plan. Site-specific signs are one means of providing information, but other means may be needed to gain the support and cooperation of area users. The different ways of gaining support and cooperation are considered in more detail in chapter 4.

Training needs can be included in the restoration plan. Restoration training (workshops or on-the-job training) and

A Sample Small-Site Prescription

Site 4 at Cradle Lake will be closed to camping. The main trail (Trail No. 1) to the site will be left open for those circumnavigating the lake. Trail No. 12, a social trail that drops down to the lakeshore, will remain open to provide access to water. The applicable reference plant community is dominated by Idaho fescue (*Festuca idahoensis*), Sitka valerian (*Valeriana sitchensis*), American bistort (*Polygonum bistortoides*), glacier lilies (*Erythronium grandiflorum*), and spring beauty (*Claytonia lanceolata*). Material containing these plant species will be salvaged as plugs from the planned trail relocation (figure 2–25). Seed from these plant species and any others in seed in this same meadow type will be collected and sown when the project is implemented. The site is 1,200 square feet (about 111 square meters), requiring 300 lineal feet (about 91 meters) of an excelsior erosion-control blanket. One oak sign with a post will be needed to close the site.

Figure 2–25— This site at Cradle Lake in the Alpine Lakes Wilderness, WA, was restored using plant material salvaged during a trail relocation project.

certification may be needed before some measures can be implemented. Include training as part of project costs.

The plan needs to include a format for documenting accomplished work and a monitoring plan. Ongoing maintenance requirements also are addressed. Refer to chapter 4, *Restoration Program Development and Support*, for additional suggestions.

Using the NEPA process, you now have a preferred alternative that will be sent out with the additional alternatives for public comment. Or, if your decision falls under the criteria for a categorical exclusion (from further documentation in an environmental assessment), you have formulated your decision (provided, of course, that the decisionmaker approves). Any further analyses, such as biological assessments (sometimes required for compliance with the Endangered Species Act) or cultural resource reports, are finalized. Formal concurrences are obtained from other agencies before the decision document is signed.

2.2.1 Considering the Time Required for Plant Propagation

Restoration projects take at least 3 years (Hanbey 1992). The first year is for completing the site assessment, formulating a restoration plan, reaching a NEPA decision, and for collecting plant material used for propagation. The second year is for implementation of management strategies, including site treatments. The third year is for maintenance of the project, including any watering, signing, and initial adjustments. Each step may take much longer.

Project implementation often takes place over the course of several years or even longer. For example, at Paradise Meadows in Mt. Rainier National Park restoration treatments have been ongoing for decades because of the challenges of managing millions of visitors in a fragile subalpine setting. The maintenance phase extends into the future, because restoration projects are a long-term commitment. Monitoring may continue over many years.

So where does collecting and propagating plant material fit in this schedule? If you have a guarantee of project funding for a multiple-year project, you may hedge your bets and collect plant material as part of the site assessment during the first year. Unfortunately, this puts the cart before the horse—you haven't even determined whether restoration will be included in the preferred alternative.

If you are collecting seed, this is really no big deal; seed is easy to collect for small-scale projects. Refer to section 3.10.8, *Working With Seed,* to learn how to collect and store seed properly. Once funding is secured, you can arrange for plants to be grown from seed, keeping in mind that it takes at least 6 months to produce transplant-sized stock (figure 2–26). Any cuttings you collect will need to be transported to a grower immediately. Some trees and shrubs are best planted as larger stock, which may take several years to grow.

If you are unsure of project funding, collect seed during the planning phase and store it. If the project is funded, deliver the seed to a grower with a goal of planting seedlings during the second year. Collect cuttings during the second

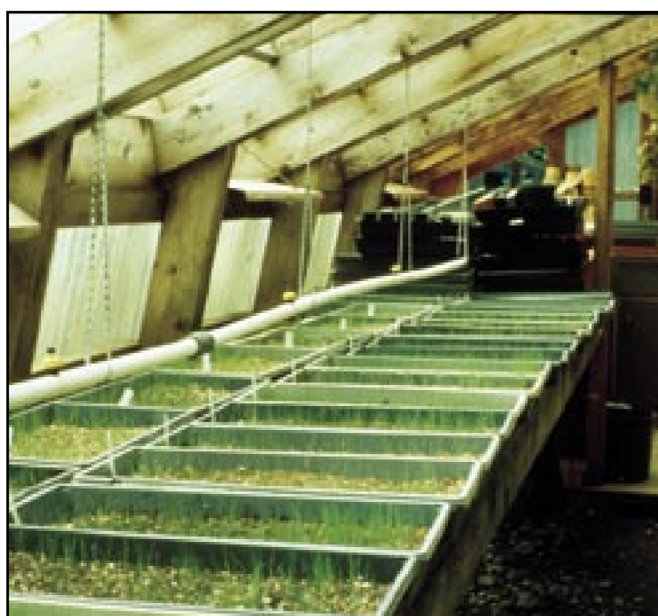


Figure 2–26—Sedges and grasses were planted during the fall in the greenhouse at North Cascades National Park, WA. They were transplanted nearly a year later.

year. During the third year, plants grown from cuttings would be interplanted with seedlings planted during the second year. You could obligate money for the third year's work during the second year with a small contract to cover the cost out of the second year's funds.

Plant storage also requires attention to timing. Your grower may have plants ready before you are able to plant. If so, arrangements must be made for plant care and storage.

2.2.2 Research Opportunities

Early in the planning process, it is worth discussing whether your project might provide opportunities for research. While a large body of research exists on restoration, there is still much to learn, especially with restoration in our remote and fragile wilderness environments.

Including a research element in the project design could change your project. For example, a research design might need to be laid out in defined plots (figure 2–27) that may not meet visual objectives. A certain number of replicates will be needed, requiring treated areas to be as similar as possible. This could require restoration sites to be selected based on research needs rather than recreation management objectives.

Research will require some areas to be marked, at least temporarily. Incorporating research objectives might require additional funding. And finally, because research may require different treatments to be compared, some treatments may fail or be significantly less successful than accepted restoration treatments.

Research projects require further consideration of the minimum requirement and minimum tool process. Can the research take place outside of wilderness? If not, will the knowledge gained by the research further the purposes of wilderness? And, if research will be conducted in wilderness, how can the project be designed to accomplish research objectives while minimizing permanent or temporary impact to the wilderness environment.

Figure 2–27—This restoration research design studied seedling emergence using five different site treatments in 10.76-square-foot (1-square-meter) cells.

Even if you don't incorporate formal research in your project, it is important to experiment with different species, new products, or different techniques on some portion of your project. Be sure to share your findings, so the art and science of restoration will continue to develop.

Example of a Graduate Study

For her graduate research study, Joy Juelson compared a control (no site preparation) to five different site preparation treatments intended to enhance seedling emergence (Juelson 2001). Her research was conducted at the dry Enchantment Lakes Basin in the Alpine Lakes Wilderness in Washington. The area averages 46 to 60 inches (1.17 to 1.53 meters) of precipitation annually, but almost all of the precipitation falls as snow during the winter months; summers are dry with little or no rainfall. Species used in the study included Parry's rush (*Juncus parryi*), black sedge (*Carex nigricans*), and partridgefoot (*Leutkea pectinata*).

Standard treatments that occurred on all plot cells included scarification, inoculation with mycorrhizal fungi, addition of organic material, creation of safe sites for seed, mulching, and weekly watering. Differences in seedling emergence (figure 2–28) were compared for the following treatments:

- Covering the site with polyethylene sheeting (Visqueen) during the germination period.
- Doubling the amount of water given weekly.
- Supplementing all missing soil nutrients.
- Supplementing only magnesium (in the form of Epsom salts) to restore cation (positively charged ion) exchange.
- All treatments combined.

Her findings generated many useful observations:

- Seedlings emerged even as the snow was melting off the sites.
- All treatments supported seedling emergence in dramatic comparison to the control. The Visqueen treatment yielded the most seedlings. The "all treatments combined" treatment yielded the least seedlings.
- During the first season, partridgefoot seedlings were more abundant than those of the other individual species.
- During the second growing season, when the plants were watered less, many of the partridgefoot seedlings died, allowing the sedge and rush to become more dominant.
- During the second season, seedlings at sites with a north to northwest aspect had substantially better survival rates than seedlings at sites with a south to southeast aspect. Plots that initially had the Visqueen treatment fared the best during the second year.

This story had a sad ending. During the third season, watering was delayed until about 3 weeks after the snow had melted. The soil dried out completely and all the tiny seedlings perished. Retaining soil moisture is a major limiting factor to restoration success in the Enchantment Lakes Basin.

Figure 2–28—Counting seedlings requires attention to detail.

2.2.3 Identifying Research Needs

What are the limiting factors to successful restoration in your environment? What are the potential detrimental effects of restoration? The following suggestions may generate additional research questions (Rochefort 1990, Juelson 2001). Also refer to appendix A, *Treatments To Manage Factors Limiting Restoration*, as a source of ideas for research or experimentation.

- **Water Limitations**—Many plantings fail because of seasonally dry conditions. Regular watering programs usually are not feasible and cost effective on remote sites. Experimentation with techniques to improve water availability (figure 2–29) for plants would be a worthwhile research endeavor.
- **Soil Treatments**—Research is needed to determine which techniques can be used to restore native soil characteristics, benefiting vegetative recovery. Treatments might address problems caused by compaction or missing organic layers and consider whether soil amendments and reestablishment of soil organisms would help solve such problems.
- **Plant Genetic Diversity**—Research is needed to identify the genetic characteristics of plant species used for restoration. This research will be used to determine scientifically the proper distances for gathering plant materials when treating a restoration site.

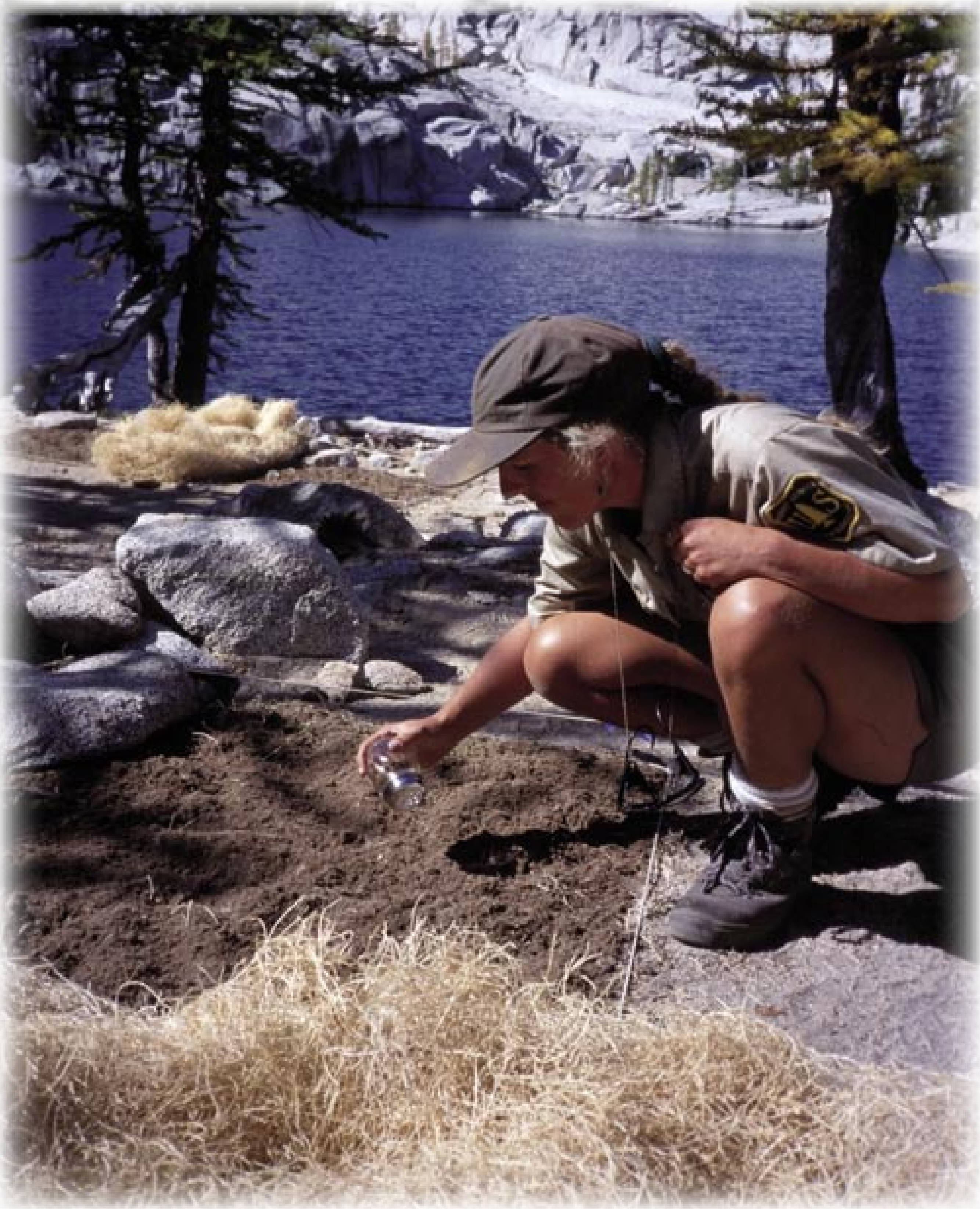
Figure 2–29—Coauthors David Cole (far left) and Vic Claassen (far right) assess water availability on a dry site with wilderness rangers T.J. Broom (in Forest Service jacket) and Gabe Snider.

- **Plant Propagation**—Research is needed to determine how to propagate species that lack propagation protocols or that are difficult to propagate.
- **Species Introductions**—Restoration projects risk introducing organisms that are not indigenous to the local area. When a site is treated, little is known about the presence of such organisms and whether they will survive in the wild. Such organisms could be in imported soil, soil amendments, or plant materials. Examples of such organisms include soil or plant pathogens, soil micro-organisms, plant seeds, plant or fungal spores, and insects.

2.3 Concluding Thoughts

Good restoration planning takes time. Your team will want to be clear on what needs fixing, why it is broken, and the best methods for repair. Your aim should be to design an integrated sustainable solution that is compatible with management objectives. Adjustments can be made over time as results are monitored.

Chapter 3



The Art and Science of Restoration

This chapter will explain the techniques (figure 3–1) used in a restoration project, providing enough technical background to get project planners pointed in the right direction. Some concepts underlying the techniques are explained as thoroughly as possible, while others are too technical to treat fully here. To address the most technical issues affecting your restoration project, recruit specialists with the needed expertise.

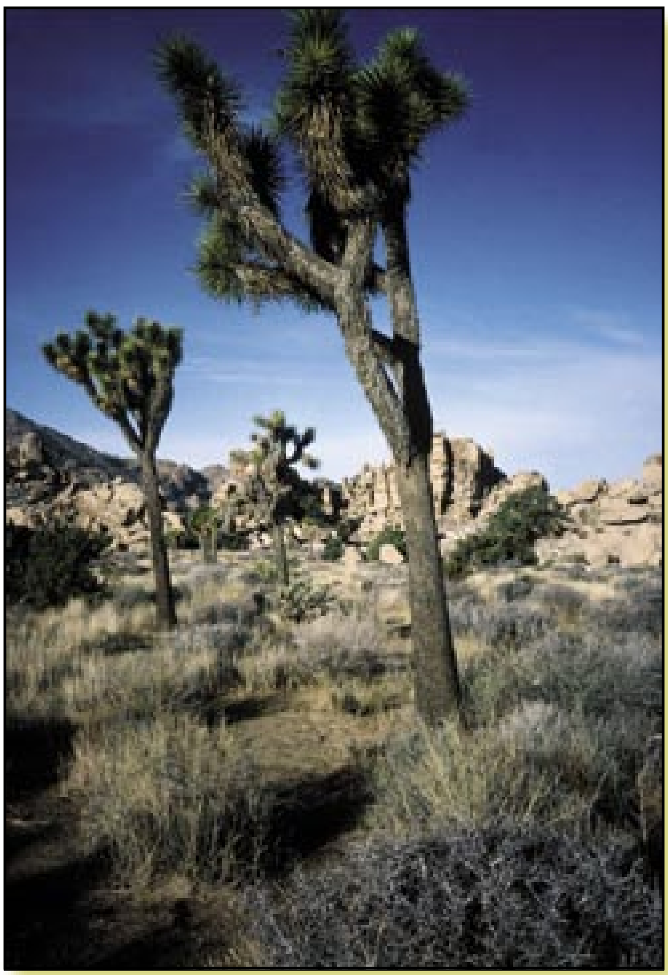


Figure 3–1—Many of the restoration techniques developed for use on arid lands also are beneficial on dry forested sites or alpine sites.

This chapter follows the sequence used when implementing a restoration project:

1. Select an appropriate plant community as a model for the restoration prescription.
2. Assess soil conditions and formulate treatments.
3. Select appropriate plant species and propagation methods (figure 3–2).
4. Identify methods for protecting the project from damaging environmental forces and human use.
5. Determine how the project will be documented and monitored.
6. Identify ongoing maintenance needs.

Figure 3–2—At Joshua Tree National Park, CA, tall pots are used to propagate deeply rooted plants native to the Mojave Desert.

3.1 Developing Site Prescriptions Based on a Reference Site

Much of the success of a restoration project involves treating the conditions that limit plant growth in the site's degraded substrate. Some of the problems with a degraded site are obvious, such as erosion or compaction. Others are less obvious, such as the reduced availability of water late in the season or changes in microbial activity. This section addresses three aspects of site evaluation:

1. Selection of a reference (example) site
2. Evaluation of the impacted site and the reference site
3. Analysis of soils and selection of treatments

3.1.1 Determining Reference Sites

One of the most difficult and important steps of the restoration planning process is determining what type of site treatment will be effective in achieving revegetation. Clues to potential treatments or target conditions are provided by selecting a suitable target plant community called the reference site, reference community, or even just reference (Clewell and others 2000). Selecting an appropriate reference site guides development of the site prescription, including the treatment of soils and vegetation.

Ideally, a representative disturbed-but-revegetated reference site that supports sustainable and appropriate vegetative cover would be selected. This reference site will illustrate the process of secondary succession—how natural systems reclaim a disturbed area. Perhaps your project is in an area that is in the latter stages of succession. In such a case, the reference site should be in an undisturbed area nearby that is representative of the plant community before disturbance.

Sections 3.1 to 3.1.1c discuss how to select a reference site. The more technical how-to information for evaluating soil condition and selecting appropriate plant species is covered in the sections on soils (3.1.2 to 3.1.6c) and plant selection (3.10 to 3.10.4).

True ecological restoration would restore the structure (species composition), process (the way ecosystem components interact), and function (overall energy flows) of the missing native plant community. Unless a restorationist has a very simple community to restore, ecological restoration may not be fully achievable, even after decades of recovery. Perhaps your goal stops short of restoration. You may be attempting to rehabilitate a site with native vegetation that can withstand ongoing use or to establish native plants on toxic mine tailings.

Fortunately, most wilderness restoration projects are small. Restoration usually addresses vegetative restoration or soil stabilization. The disturbances may not impair ecosystem processes and function. Our goal may not specifically include recovery of habitat for animal species. For a restoration site to fully recover its vegetative community, often soils and the associated animal species must recover as well.

To begin evaluating a site, become an observer of the landscape and ecosystem. Identify distinct plant communities within your ecosystem (figure 3–3). Notice how the vegeta-

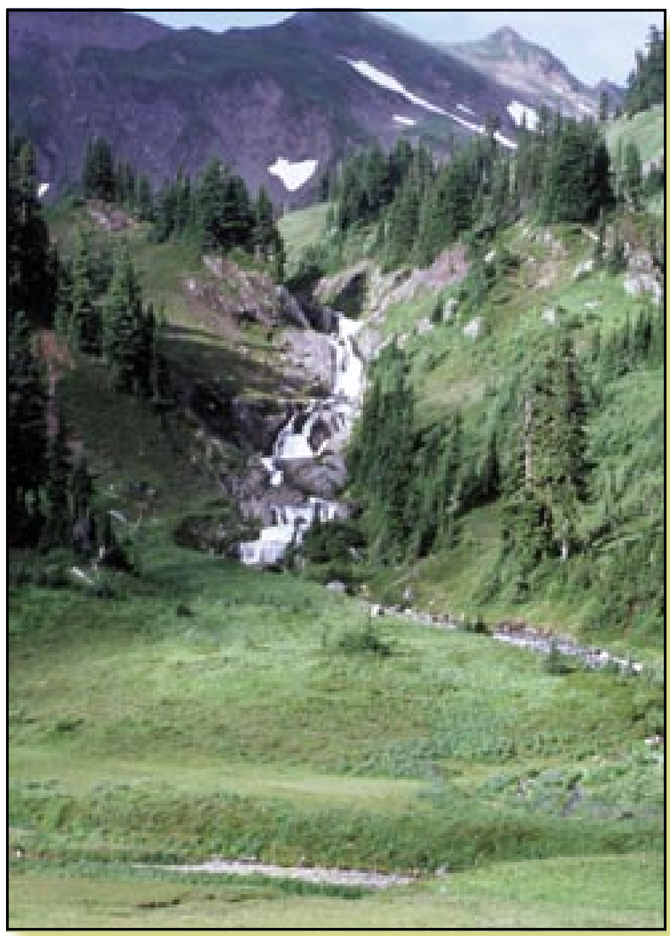


Figure 3–3—Most landscapes are comprised of many different plant communities, each adapted to features such as slope, aspect, soil depth, and water availability. Understanding how your restoration site fits into landscape patterns is a critical part of planning.

tion changes from north to south aspects, from sun to shade, from slopes to flat areas, from moist shorelines or meadows to dry knolls or ridges. Notice patterns in the vegetative layers: the juxtaposition of trees, shrubs, forbs, and grasses, and even mosses and lichens. Examine how the soil profile changes from one plant community to another.

Pay attention to signs of animal life: rodents, insects, worms, and others. Locate disturbed areas that have recovered by themselves, such as trail cutbanks, revegetated ditches leading from drain dips, craters behind windthrown trees, areas where animals have burrowed, slides and slumps, or old burns. An ecologist familiar with your ecosystem will help you interpret the processes you observe.

3.1.1a Choosing a Reference Site

Conceptually, the steps for selecting a reference site are simple. But understanding ecological processes and patterns is not. Your interdisciplinary team will help you bring the pieces of the ecological puzzle together. Together, the team will work to identify a reference site that reflects project goals and perhaps even sites with intermediate communities that represent steps during succession that lead toward the communities at the reference site. The Society for Ecological Restoration Science and Policy Working Group (2002) describes this approach as identifying an ecological trajectory to recover natural conditions on a site. If your short-term goals do not match your long-term goals, your prescriptions should attempt to meet your short-term goals while moving the site toward your long-term goals.

Choosing a reference site is easily confused with trying to freeze a moment in time. Don't think of the reference site as a precise set of conditions. Rather, think of it as a range of natural conditions found on similar undisturbed or disturbed-but-revegetated sites. The restoration project will be designed to move the disturbed site toward this range of conditions. More than one reference site may be needed to express this range of conditions.

3.1.1b Identifying Undisturbed Reference Sites

It is virtually impossible to reconstruct the exact conditions of a site or to determine the exact vegetation that was on a site before it was disturbed. However, several sources of information can be the basis for ecological conjecture. The most important sources of information are nearby undisturbed areas that share slope, aspect, moisture regime, canopy cover, and similar features with the disturbed site.

To select reference sites, find areas that are well away from concentrated human use. Based on research conducted by the U.S. Department of the Interior National Park Service at Glacier National Park, a loss of species diversity was documented up to 6½ feet (about 2 meters) on either side of a trail (Hartley 2000). More than one similar area should be identified to form a composite picture of the missing vegetative community and its associated soil structure and other habitat components. In addition, the disturbed site should be examined for any surviving remnants of native vegetation.

The vegetation surrounding the disturbed site may or may not provide helpful information. If the features of the area surrounding the disturbed site are distinctly different from those of the disturbed site itself, the vegetation is likely to differ as well and the surrounding area may not be appropriate for a reference site.

For example, in the Cascades, Olympics, and Northern Rocky Mountains, typical subalpine parkland is comprised of a mosaic of vegetation types. The vegetation found in clumps of mature trees includes shrubs such as currant (*Ribes)* and rhododendron that don't grow on open slopes in full sun. Ground cover within the tree clumps may include plants such as trailing bramble (*Rubus*), Sitka valerian (*Valeriana sitchensis*) or wood rush (*Luzula*). Partridgefoot (*Leutkea pectinata*) often dominates recent disturbances and seems to like areas of partial shade. Nearby sloping meadows may be an early successional community of forbs and grasses, a later successional community of heather and huckleberry, or a mix of both. Flat areas at the bottom of slopes may be thick with the moisture-loving black sedge (*Carex nigricans*). But the plants that really like their feet in the water along boggy lakeshores or streambanks may be marsh marigold (*Caltha*) and different species of sedge.

The species of plants found growing on the tops of knolls and ridges will be those adapted to drier conditions, thinner soils, and more wind. Only a few plants, such as the early colonizing Parry's rush (*Juncus parryi*) seem to grow in almost all of these settings. As an illustration of the complexity of vegetation types within an ecosystem, Roger del Moral (1978) identified 21 different recognized plant community types, including 11 forested community types and 10 alpine community types in his studies of a subalpine basin in the North Cascades (figure 3–4).

Sometimes it is necessary to view information in a broader historical context. For example, if an entire land-scape has been changed because of a human-caused distur-

Figure 3–4—Roger del Moral identified 21 different recognized plant community types in a subalpine basin in the North Cascades, WA, including 11 forested communities and 10 alpine communities (del Moral 1978).

bance, such as grazing or excessive trampling, historical records and range science may provide additional clues to the vegetative community before disturbance. Helpful sources of information might include historical photographs, vegetative surveys, field notes, or species lists.

On landscapes disturbed by grazing, different plants respond differently to grazing pressure. Although the most delectable ice cream plants may once have been common, they may be underrepresented or even missing after grazing. Species favored by disturbances, such as pussytoes (*Antennaria*), will be more abundant (figure 3–5). In such situations, it may be appropriate to select a disturbed-but-revegetated reference site rather than a pristine, undisturbed site.

3.1.1c Identifying Disturbed-But-Revegetated Reference Sites

Many project sites slated for restoration are so altered that plants from the historical plant community may not thrive there, even after being replanted. It is helpful to distinguish between a human disturbance that resembles a natural disturbance and a disturbance that results in an unnaturally stressful environment for reestablishing plants. If site conditions can be made more favorable, early- to mid-seral species that are adapted to disturbance are likely to succeed. If site conditions cannot be improved, it is important to select a reference site with a plant community adapted to these types of environmental stress. Few plants are adapted

Figure 3–5—In the subalpine landscapes of the Pacific Northwest, concentrations of pussytoes (*Antennaria*) indicate where large bands of sheep took their afternoon siestas. The invasion of pussytoes represents secondary succession, the succession that takes place after a vegetated landscape is disturbed.

to withstand both high disturbance and high environmental stress (Chapin 1992). The factors likely to limit restoration success need to be identified (see appendix A, *Treatments To Manage Factors Limiting Restoration*). Reference sites should be selected that best portray the site characteristics and the factors that may limit success.

Examples of naturally disturbed areas to examine include slumps or slides, alluvial fans, avalanche paths, areas near retreating glaciers, recently flooded areas, and so forth. Trail or road cutbanks or the disturbed site itself also may be good indicators of potentially appropriate plant species for the restored site.

Damage to the soil structure and associated water relations often are the biggest challenge to reestablishing a desired plant community. Such challenges might include: loss of the organic soil layers (including micro-organisms), increased compaction, change in pH, increased toxicity, change in slope or drainage patterns, past or active erosion (figure 3–6), and changes in soil texture. Treatments, such as importing topsoil, soil amendments, or fertilizer, bear scrutiny. Consider the resource tradeoffs and remember to apply the minimum requirements principle. Additional environmental factors affecting plant establishment might include extremes of heat or cold, wind, grazing animals, and so forth.

Figure 3–6—This sod continues to be eaten away by the wind and the burrowing of pocket gophers in the Alpine Lakes Wilderness, WA.

Technological feasibility may limit some aspects of restoration, such as which tools might be used on remote sites. For example, if reestablishing the slope angle with heavy equipment is inappropriate or infeasible, the original plant community may be replaced with a different community. In wilderness, the option of using motorized or mechanized equipment would require an analysis to determine whether these methods are the minimum requirement for accomplishing project objectives. There are no easy cookbook answers to such ethical dilemmas. Each project must weigh such factors on a case-by-case basis.

Some dominant plant species are difficult to reestablish through restoration. For example, restoration of heather communities (figure 3–7) is problematic in the Pacific Northwest, as is the reestablishment of creosote bush in the deserts of the Southwest. Fortunately, reliable restoration protocols are being developed by the U.S. Department of the Interior National Park Service for these environments. See appendix C, *Detailed Propagation Methods for Beargrass, Heather, Huckleberry, and Partridgefoot*, for more information.

Figure 3–7—Matt Albright, greenhouse manager for Olympic National Park, WA, has successfully propagated a number of difficult species in the heath family. Several of his protocols are in appendix C.

Continued patterns of human use also may influence the selection of a reference site. If the project goals include allowing continued human use, the reclaimed site will require a resilient vegetative community. For these situations, find native plant communities nearby that mimic the conditions you must work within to reestablish vegetation. Plant communities on these reference sites might have revegetated themselves after a natural disturbance (such as fire), or they might be revegetating themselves naturally after a human-caused disturbance (such as an abandoned and now recovering campsite). These plant communities probably will represent an earlier seral community than that at the impacted site, but otherwise have similar site characteristics, such as topography, soil development, and shade.

For example, at Denali National Park in Alaska, road cutbanks slowly colonize with the same plant species that are found on naturally unstable slopes. The park decided to treat cutbanks using species that grew on naturally disturbed slopes (Densmore and others 1990).

In their work reclaiming toxic mining spoils on alpine sites in the Intermountain West, Brown and Johnston (1980) sought to reestablish a native stand of vegetation that "will resemble the posture of a native plant community when it becomes self-reproducing, stabilizes the soil on the site, and reaches a successional status involving native plant species of the area." They acknowledged that recovery could take decades or even centuries, making it impossible to prescribe a mandatory timeframe.

The next step is to describe the assemblage of plant species, their relative abundance, and the soil structure at the reference site. If reference examples exist in the project area, note their location so they can be referred to for planning, project implementation, and monitoring.

If determining a reference site seems daunting, you can take some comfort from knowing that if you select the "wrong" plant species, they may eventually die out. Although it might be discouraging to lose some plants, letting nature shape the result is what restoration is all about.

3.1.2 Comparing the Reference Site and the Restoration Site

This section will help you identify conditions at the reference site that will serve as a realistic example of conditions at the impacted site after it has been restored.

Comparing Soils

For many wildland situations, the required or desired soil conditions for sustainable plant growth are not well known. Soil data and target nutritional or soil chemistry values from agricultural and horticultural systems may not be appropriate for revegetation projects in wildlands. Agricultural systems tend to have soils with nutrients in highly available forms. While wildland soils tend to have larger total nutrient contents, the nutrients are not as readily available as those in agricultural soils. The characteristics of wildland soils are best modeled by choosing a suitable reference site that represents the intended soil characteristics of the impacted site after treatment.

The following sections of this guide outline how to use topography, mineralogy or geology, general soil profile, and soil surface conditions to evaluate soil characteristics. More detailed lab analyses can provide technical nutrient data, but a good field evaluation can provide many important clues to site condition, soil condition, and the potential need for treatment. At many disturbed sites, field evaluations may be good enough for treatment. Plant community types or indicator species can be excellent indicators of long-term soil functions, because they indicate the integrated response of plants to site conditions over many seasons.

Evaluating soils on a field site requires a different investigative approach than the approach used for counting plants or species. The processes are often more important than a particular quantity. For instance, a wildland soil's water-holding capacity is more important than its water content at any given time and the organic matter cycle is more important than the soil's short-term nitrate content.

Even though we may measure some of the soil characteristics and contents in lab analyses, the processes that support

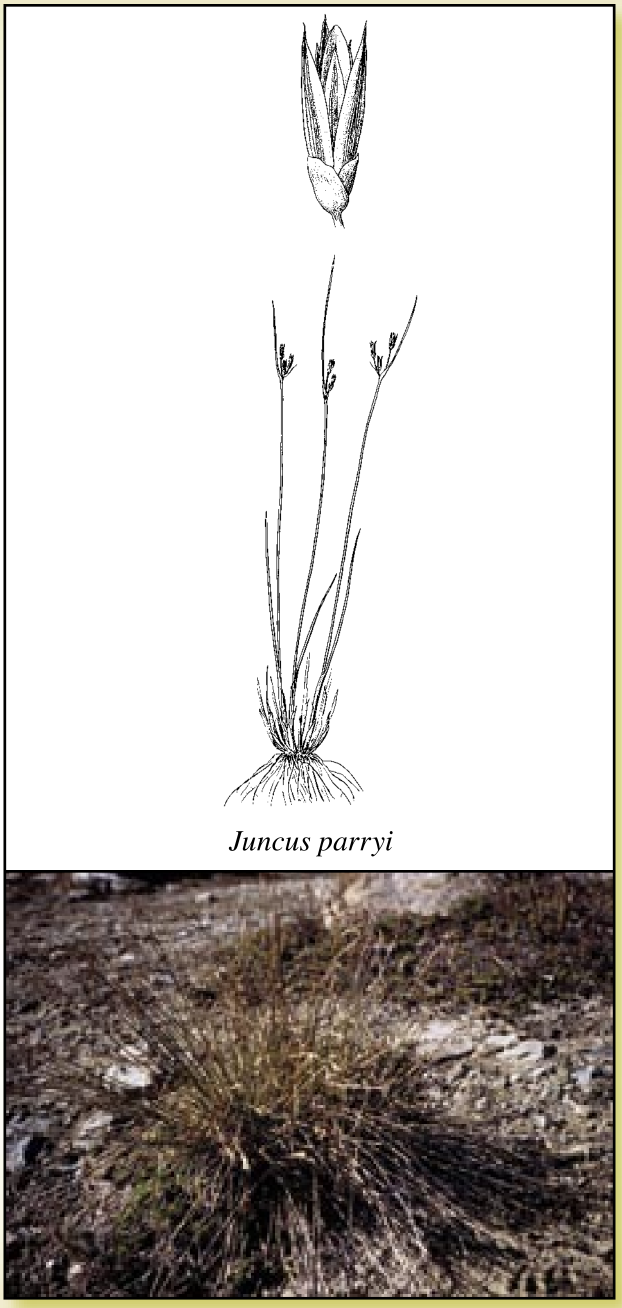
Selecting a Reference Site at Upper Florence Lake

Upper Florence Lake in the Alpine Lakes Wilderness sustained heavy sheep grazing for 70 years, resulting in substantial soil erosion and loss of vegetation (figure 3–8). The forces of wind and water erosion, as well as recreational use, continue to degrade this site. An adjacent meadow would indicate that the historical plant community was a well-developed heather and huckleberry meadow interspersed with sedges and herbaceous species. However, replacing the amount of topsoil needed to support a heath community would not be realistic. Several plant species have volunteered in the disturbed area, including black sedge (*Carex nigricans*, figures 3–9a and 9b), Parry's rush (*Juncus parryi*, figures 3–10a and 10b), and partridgefoot (*Leutkea pectinata*, figures 3–11a and 11b). These species would suggest that a nearby sedge meadow or a south-facing slope with partridgefoot could serve as a reference site.

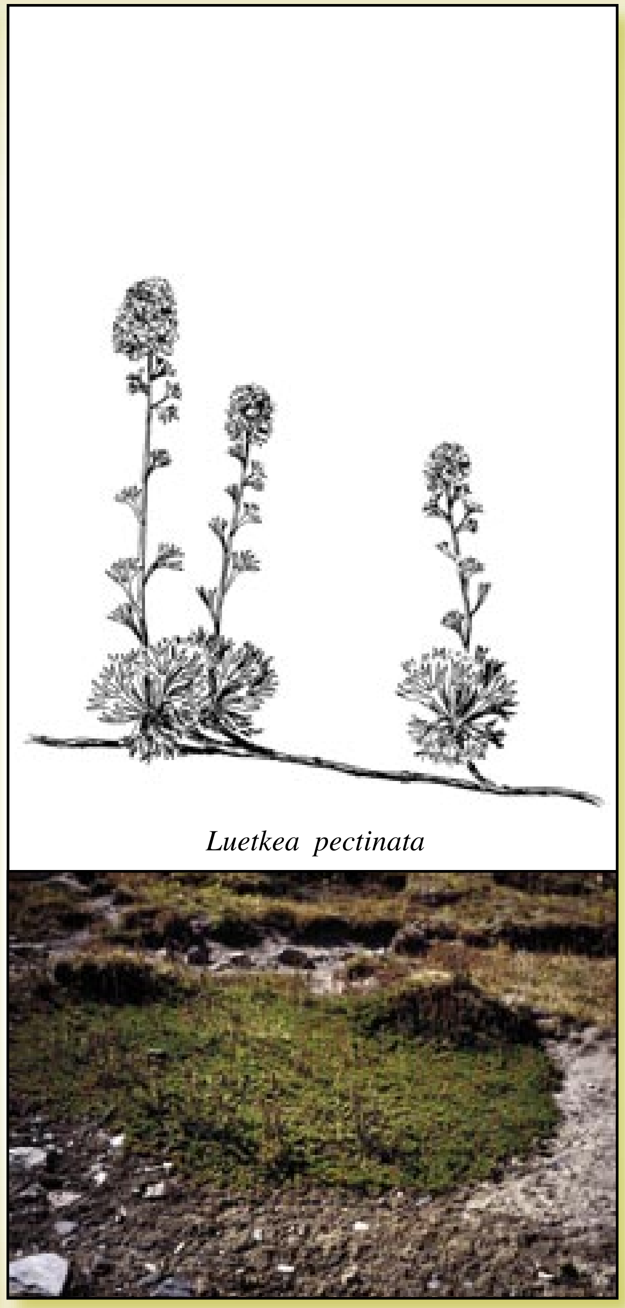
Figure 3–8—Heavy sheep grazing began the process of erosion at upper Florence Lake in the Alpine Lakes Wilderness, WA.

Carex nigricans

Figures 3–9a and 9b—Black sedge (*Carex nigricans*), drawings (top) and photo (bottom). Drawings courtesy of the University of Washington Press (Hitchcock and Cronquist 1976).



Figures 3–10a and 10b—Parry's rush (*Juncus parryi*), drawings (top) and photo (bottom). Drawings courtesy of the University of Washington Press (Hitchcock and Cronquist 1976).



Figures 3–11a and 11b—Partridgefoot (*Leutkea pectinata*), drawing (top) and photo (bottom). Drawing courtesy of the University of Washington Press (Hitchcock and Cronquist 1976).

plant growth long after irrigation treatments or fertilizer amendments have ended are most important for long-term, sustainable soil regeneration. To determine whether the soil characteristics are appropriate for plant growth, conditions must be evaluated based on time scales that range from centuries (soil profile development), to decades (organic matter accumulation), months (water storage and microbial growth), days (nutrient cycles), or minutes (infiltration and surface erosion from the impact of raindrops).

While all soil characteristics interact, they can be assessed independently, allowing deficient conditions to be corrected without creating imbalances in related conditions. As each characteristic is considered below, look for ways that one characteristic influences another to provide an integrated network of plants, fauna, soils, and watersheds.

Landforms

Understanding how soils are influenced by landform position will help you find a suitable reference site for the impacted site.

The position of the selected site within the topographical landscape provides the first clues to the characteristics of the soils in an area. Soils that developed directly on the underlying rock (figure 3–12) are said to have been formed on residual parent materials (geological substrates) and can be expected to derive their chemical and textural characteristics from the underlying rocks.

Figure 3–12—The green serpentine soils on these open slopes formed from the decomposition of parent material.

Soils that form on transported substrates develop on parent materials that have been washed downstream, carried by glaciers (figure 3–13), or blown by the wind (aeolian deposits). The soils will acquire many of the characteristics of the transported source materials. Such soils often occur on low-lying areas. They may not resemble soils that developed on the local bedrock, even though the bedrock rises just a short distance away.

Figure 3–13—Glaciers transport glacial till.

How long a soil has been forming on a site influences how strongly the soil horizons will have developed. Some residual soils are very stable, remaining in place for hundreds of thousands of years. In these older soils, thick clay layers and well-developed soil horizons are generated as rocks weather and soil processes continue. Restoration of a disturbed site for revegetation of a plant community requiring these soil conditions requires careful replacement of various horizons of soil, paying attention to the thickness of each horizon.

Examples of sites requiring careful attention would include:

- Low-lying sites, such as vernal pools that require restricted drainage and standing water for certain periods in the spring.
- Level upland sites with high clay content that store moisture that is available for plants during periods of drought.

A recently formed soil that has had little development of soil horizons can be regenerated after disturbance with relatively little treatment, because little soil development has occurred at the site. An example of such a soil would be the coarse soil with poorly developed horizons often found on glacial deposits or along riparian areas subject to frequent flooding.

Landform position also influences soil development. Soils on lower slopes are commonly deeper than soils on upper slopes, because gravity and water remove soil from the upper slope and deposit it lower on the slope. Soils in the bottom of old swales or draws can be especially deep compared to soils only a few feet (a meter) on either side of the drainage. Often, low-lying areas are more heavily impacted by human use than adjoining slopes because campsites and social trails tend to be more common on flatter terrain.

Unless rock is well fractured, soil drainage and plants' rooting depths often are limited by underlying layers of solid rock. Intensely fractured rock may not have much nutrient value, but it offers roots access to deeper water reserves during drought. Soils that form on transported substrates with fine-textured horizons (such as ash) overlying coarse-textured horizons (such as gravel) have a special limitation regarding moisture distribution. Water is retained in the smaller pores of the upper horizons and it may not flow downward into the coarse sandy or gravelly lower horizon. Roots often do not grow into the coarse lower horizon because it is comparatively dry. Such soils are found in the Enchantment Lakes Basin in the Alpine Lakes Wilderness of Washington, where a fine-textured soil from ash fall overlies coarse glacial deposits (Juelson 2001). This problem is discussed in more detail in section 3.1.4a, *Soil Texture and Pore Size*.

The aspect of a site can influence the depth of soil development. Soils on the north (shady) side of steep slopes tend to be cooler and moister. They have more plant growth and deeper soil development than slopes on other aspects. If the site is at high elevation, north-facing sites may be colder and hold snow longer, in which case soil development will not be as deep as on warmer, south-facing slopes.

Sometimes the fine and coarse sediments laid down by streamflow mimic soil horizons, giving the impression of soil development where there is none. The way to distinguish soil profile development from silt or clay-rich layers that were laid down by geological processes such as streamflow is to observe the pattern of layering over a broad, exposed slope—a slope about 15 to 30 feet (about 4.5 to 9 meters) wide or wider. Road cuts or exposed streambanks are the easiest way to see these formations. A shallow pit at the upper shoulder of the slope will show a profile that can be compared with a (usually) deeper soil profile lower on the slope.

In contrast, if the layers tend to follow the surface of the landform with its hills and swales, the layers would be attributed to soil-forming processes. If the layers are horizontal or follow the pattern of the local geological layers or fluvial (stream) deposits, they probably were laid down by geological processes. Another clue is that transported sediments often have patterns of alternating coarse and fine layers as a result of fluctuations in moisture (rainfall erosion versus dry ravel) or depositional energy (high or low streamflows).

Most prospective wilderness restoration sites, such as campsites, are likely to be stable, because they may be on relatively level ground. In other situations, slope failure could become an issue, such as in areas with excessive runoff, road cutbanks, mine tailings, or slopes undercut by old roads, trails, or streams. A soil scientist or geomorphologist on your team can evaluate the potential for slope failure in such areas. If slope instability is induced by human activities, slope stabilization may be addressed in the site prescription. Be careful to distinguish surface erosion issues from geotechnical issues that are larger in scale and that are not directly treatable by revegetation.

Mineralogy

You need to confirm that the mineralogy of the impacted site matches the reference site.

Observe the geology of the general area, or at least of the substrates on which the soils are forming. Soils derived from sandstones or granites tend to have coarse, sandy soil near their weathering sources (figure 3–14). If the area has had glacial activity, the fine materials may have washed into the site, making the soils finer, or the fine materials may have been washed away, making the soils coarser. Look at the sand grains with a magnifying lens. Have the grains been rounded by water? Or are the edges angular and cracked, as they would be after being frozen and ground down a slope by a glacier? Do the particles contain vesicular cavities (small gas bubbles) formed during rapid cooling of molten material after a volcanic eruption?

Figure 3–14—The coarse, sandy soil of this high Sierra basin in the John Muir Wilderness, CA, is derived from granite. In restoration prescriptions, the parent material at the reference site should match the parent material at the restoration site.

Try to determine whether the region is derived from intrusive volcanics (granites or diorites with large crystals), or extrusive volcanics (fine-grained andesites or basalts). The intrusive (granite-like) materials have larger crystals and the rocks as a whole may physically weather and crumble more rapidly. The extrusive (ash-like) materials have smaller crystals so that rocks tend to chemically weather more quickly. Soils derived from extrusive materials will be deeper or have more clay. The parent material and mineralogy will be related to general trends in the water-holding capacity of soils and the abundance or scarcity of some soil nutrients, topics that will be covered later.

Soil Profile Development

You will need to evaluate the soil profile and soil formation at the impacted site, including the soil horizon development and the volume of soils in each horizon, comparing these soil characteristics to those of the reference site.

Compare soil profiles by digging at least two soil pits, one at the impacted site and one at the undisturbed reference site (figure 3–15). As described previously, the reference site may be a site that had previously been disturbed but is now revegetated. This type of comparison provides a general

Figure 3–15—Soil pits should be excavated to the depth of root penetration.

estimate of how much the soil has degraded and how much treatment is needed to reestablish plant growth. Because organic matter and soil structure develop over many hundreds of years, an undisturbed native reference site may provide an unrealistic goal for soil regeneration spanning only a few years. For example, a dry, south-facing slope that develops a thinner soil may be a closer representative of the outcome at the project site than a deep, rich soil that has formed for many years on a valley floor.

Ideally, pits should be excavated to the depth of root penetration. Because many plants are deeply rooted, that's not always practical. Usually most of the important aspects of the horizons can be observed in the top 3 feet (1 meter) of the pit or perhaps in the top 12, 20, or 28 inches (300, 500, or 700 millimeters) in shallower soils. For better lighting and photos, orient the pit so that the wall facing you will be in sunlight when you're done digging. A pit about 20 inches (500 millimeters) across is usually wide enough to observe soil characteristics. Some soils have repeated patterns of mounds and swales, requiring careful placement of the pit.

Estimating the Volume of Coarse Fragments

Keep a pile of the coarse fragments that are excavated from the pit. Coarse fragments include:

- Gravels—Smaller than 3 inches (75 millimeters)
- Cobbles—3 to 10 inches (75 to 250 millimeters)
- Stones—Larger than 10 inches (250 millimeters).

Keep these separate from the finer soil excavated from the pit and estimate the volume of the coarse fragments as a percentage of the whole soil volume. For example, if the pile of rocks is half the volume of the pile with the rest of the soil, the soil would be 33-percent coarse fragments and 67-percent field fines. The coarse fragment (rock) content of a soil reduces the nutrient content, but can allow deeper rooting and can influence plant community patterns.

When samples are taken to the lab, the true fine soil—soil with particles smaller than the head of a pin, about 0.08 inch (2 millimeters)—is sieved out. The rocks and gravels are assumed to have little nutrient content and to dilute the fertility of the fine soil, but in some soils, even the coarse fragments (coarse woody debris and decomposed rock) have significant water-holding capacity or provide important nutrients. In such cases, they should be considered part of the plant community's soil resource (Whitney and Zabowski 2004; Jones and Graham 1993).

Soil Horizons

If you look in a soil pit or on a roadside cut, you will see various layers in the soil. These layers are called soil horizons (see figure 1-14). The arrangement of these horizons is known as a soil profile.

The O or Organic Horizon

If the top horizon has more than 20-percent organic carbon, it is called the O horizon. This horizon includes dead material from plant leaves and roots, invertebrate animals, and micro-organisms. Undecomposed plant material on the soil surface is called litter, which decomposes into small pieces called duff. Beneath the layer of undecomposed plant material may be plant material that has broken down into small, unrecognizable pieces and organic residues. This material is called humus. It is usually a dark color and feels slippery or waxy.

While humus generally represents a very small portion of the soil profile (a few percent or less), it performs critical functions, such as holding water, maintaining a crumb structure, contributing nitrogen, and making nutrients more available to plants (Brady and Weil 2002). Humus also benefits other soil organisms, especially the Actinomycetes (a type of filamentous bacteria that creates the "earthy" smell of rich soil). Organic matter in the soil also reduces formation of physical soil crusts and reduces runoff.

Not all natural, undisturbed soils have organic matter horizons. Areas such as deserts or alpine fellfields (rock-strewn areas above timberline) may be so sparsely vegetated that there is very little leaf litter and no humus layer. Desert shrublands may have organic matter distributed in patches under shrubs, with none between the shrubs. Semiarid lands have from just 0.5- to more than 8-percent organic matter in their soils. Tropical areas also may lack organic matter in the soil because organic matter breaks down so quickly in the warm, humid climate.

High-elevation forested areas with little soil development may accumulate organic materials in a thicker mat in the surface horizons, because materials decompose so slowly in these cold, dry areas. Disturbed areas in the Enchantment Lakes Basin of Washington had a 0.6-inch- (15-millimeter-) thick layer of duff, but foot traffic and lack of plant growth had eliminated this layer from areas that had been impacted by camping (Juelson 2001).

The organic horizons have technical names that are used in soil survey maps. These horizons are sometimes labeled from the top down as: Oi (fresh, undecomposed plant litter), Oe (distinct plant parts, but partially decomposed to fibers), and Oa (unrecognizable plant parts and humus).

The A or Topsoil Horizon

The A soil horizon is the top mineral soil horizon, meaning that it has less than 20-percent organic carbon. The A horizon is rich in organic matter that has leached from the O horizon, giving topsoil a dark brown or gray color. This horizon has the most biological activity, contains much of the soil's fertility, and allows rainfall to infiltrate into the soil.

Infiltration of water from rainfall and snowmelt depends on a soil's texture. Infiltration will be relatively rapid if soil texture is coarse or if individual soil particles have formed larger aggregates, separated by drainage pores. The size of these aggregates ranges from less than 0.04 inch to over 0.4 inch (1 to 10 millimeters) in diameter. The aggregates are shaped like small bread crumbs or popcorn.

If the A horizon is impacted or disturbed, some or all of the horizon may be lost. Foot traffic on the O or A horizons will grind these layers to dust that can blow or wash away rapidly. Finely powdered surface horizons indicate mechanical damage (traffic), even if they have not yet eroded away. When the aggregates are crushed, the soil pores are smaller, decreasing infiltration and increasing overland waterflow and surface erosion.

After excavating the soil pits, examine the exposed wall, looking carefully for small horizontal lines or fracture planes between packed or compacted soil (called platy structures). These horizontal structures form when soils are compressed while they are wet, as happens on a trail. The structures indicate loss of drainage and shallower root penetration. Scarification (surface tillage) can disrupt these platy structures, but unless organic matter is incorporated into the soil, the platy structures will quickly reform. If the soil has salt problems, white crusts will form on the surface of the A horizon or on organic matter in the O horizon.

You should observe the soil profile for signs of biological activity, paying special attention to the A horizon. Soil organisms are found primarily in humus, rotting wood, and the upper soil layers. Fungi have root-like structures underground (called hyphae) that form intricate webs (called mycelium). A fungal mycelium is readily observed as white or yellow web-like tissue in the soil or rotting wood. Mushrooms are the mycelium's fruiting bodies. Mushrooms sprout when the soil reaches appropriate moisture and temperature levels. Insects, worms, or rodent activity are also signs of biological activity. Large pieces of rotting wood are critically important to the survival of fungi and arthropods (invertebrates such as insects and spiders). Rotting wood stores water long after the soil surface moisture has dried out.

In the Enchantment Lakes Basin of Washington, the A soil horizons at undisturbed areas had well-aggregated granular or crumb soil structure, while the impacted sites had platy soil structure, indicating compaction from foot traffic (Juelson 2001). Soil aggregates in the undisturbed soil provided more rapid infiltration of surface moisture and allowed roots to grow deeper on these droughty sites.

Perry and Amaranthus (1990) provide another dramatic example of soil degradation when fragile soils are disturbed. A highly productive forested site on decomposed granite soils in the Oregon Cascades was clearcut for timber. The site was treated with herbicide several times to reduce brush cover. Without plant cover and the organic matter plants provide, the aggregates degenerated and the coarse soil lost its structure. The soil's ability to infiltrate water decreased and the nutrient-rich topsoil horizons washed away. The formerly productive forested site then only supported scattered annual grasses, ferns, and manzanita. Restoration efforts involved replanting the correct tree species and inoculating the soil with mycorrhizal fungi.

Did You Know?

About 25 percent of the total root biomass in a tall-grass prairie (figure 3–16) dies each year, contributing organic matter to the soil. The drier short-grass prairie contributes 50 percent of its root biomass to the soil's organic matter each year, but the total root biomass in the short-grass prairie is less than in the tall-grass prairie.

Figure 3–16—Prairie junegrass (*Koeleria macrantha*). Photo by J. Lokemon, Northern Prairie Wildlife Research Center, U.S. Department of the Interior, U.S. Geological Survey.

The E or Leached Horizon

The next soil horizon in coniferous forests is the E horizon, which is created by rapid loss of clay minerals, leaving a light-colored, sandy layer under the A horizon. These horizons are nutrient poor, and may contribute to unique communities of stunted or endemic plants. Many soils do not form an E horizon.

The B or Subsoil Horizon

As soils develop, clays, carbonates (lime), or salts gradually leach from the A horizon to the B horizon. In a soil pit, the crumb structure of the A horizon will be replaced by larger, blockier structures called blocks or prisms (up to 12 inches or several hundreds of millimeters in diameter). B horizons often are more intensely colored (brown, yellow, or reddish) than the A horizons.

Because the B horizon has higher clay content, it becomes the reservoir of moisture for plant growth during droughty seasons. If the A horizon has been lost because of erosion, the B horizon is exposed. This makes revegetation difficult, because the higher clay content of the B horizon can prevent infiltration. Unless the exposed horizon is modified to make it function more like an A horizon, plants may find it difficult to become established and grow adequate roots.

The C or Parent Material Horizon

The C horizon is little affected by soil-forming processes. If it is comprised of transported sediments, it will be loose, unconsolidated material. If the soil is forming on residual bedrock, the C horizon will be weathered enough to be dug with a shovel. On severely impacted sites with extensive erosion or landslides, the C horizon is the exposed soil that must be revegetated.

Observe how plants grow on nearby soils with simple A/C horizons (a thin A horizon over the C horizon) because this may be the only possible way to remediate remote or large and severely impacted sites. These simple A/C soil systems can be made to work over time, but plant communities growing on such simple soil systems will not develop in the same way as plant communities growing on complete soil systems.

If subsurface rocks are exposed at the site, look for ways to incorporate them into site design. They could be used to provide a hardened surface that can resist erosion and handle more foot traffic. The rocks can be used to help delineate sites or paths or to improve the microclimate for plants.

Sometimes layers of volcanic ash show up as reddish or gray bands (figure 3–17) separating the dark organic layers. Such soil profiles may mean that organic matter accumulated at an A horizon before an eruption buried that surface. Organics accumulated at the new surface, regenerating an overlying A horizon. These buried horizons could be used to cover exposed subsoil horizons. They may not be biologically active, but may contain residual organic carbon and may have a particle size distribution that is more suitable for plant growth than an exposed B horizon. You might consider using these buried horizons for restoration if you have opportunities to salvage soil.

Figure 3–17—The distinct band of light gray ash exposed just below the vegetation in this damaged campsite is Mount Mazama ash that was deposited 6,600 years ago. Tens of thousands of years of soil development were wiped away when a careless camper carved this tent spot out of a hillside.

When you examine an impacted site, determine which soil layers are missing relative to the reference site, and whether it is feasible to replace the missing layers. A change in soil depth (known as soil potential) probably will change the types of plants that can grow on a site. In some cases, as soil depth is lost, the same species may grow on the site but the plants may be smaller or may be spaced farther apart. In some cases, the impacted site (which could be an eroded trail) needs to be brought back up to grade. The project design should specify the type and amount of each soil layer needing replacement.

3.1.3 Evaluating the Surface Condition of Impacted Sites

The surface condition of the impacted site, including patterns of crust formation, compaction, erosion, and slope stability, should be compared to that at the reference site.

Soils typically will be covered with a layer of plant litter and a fine, powdery layer of decomposed organic materials. If this layer is at the reference site, but is not at the impacted site, why is it missing? Does its absence indicate the zone of disturbance or a normal difference in soil formation?

Be cautious. Some natural areas, such as the rocky pavement of desert areas, do not have an organic layer. In such cases, the mineral surface of the ground may be exposed, but the upper sides of undisturbed stones and gravels probably have a dark patina. Because the patina takes a long time to form, it indicates a landscape that is relatively undisturbed.

Organic-rich layers may be present under plant canopies or in the lee area downwind of plant clumps, but not in the open areas between plants. Biological crusts (see section 3.1.3c, *Evaluating Biological Soil Crusts*) can help determine whether such areas have been disturbed. In alpine areas, lichens growing on rocks may indicate that the area has not been disturbed for many years (figure 3–18).

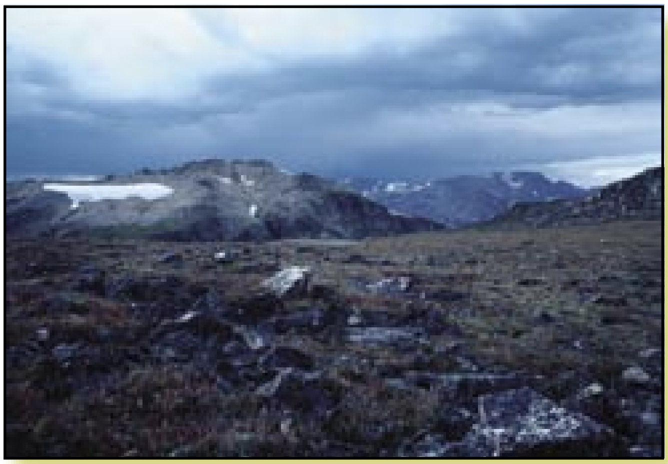


Figure 3–18—The presence of well-established lichens on these rocks atop the Beartooth Plateau, MT, suggests that they haven't been disturbed for a long time.

Another indicator of erosion is the presence of lag gravels. These lag behind when the fine soil surrounding them erodes away—the lag gravels often form a pebble pavement (figure 3–19). To confirm the presence of lag gravels, check the soil horizon to see whether more gravel is on the surface than in the next lower horizon.

Figure 3–19—Erosion has left behind a series of terraces and deposits of lag gravels in areas once grazed by sheep in the Alpine Lakes Wilderness, WA.

The soil may have geological bands of gravel deposits. In such cases, there should be other examples of soil deposition elsewhere in the soil profile, such as fine and coarse bands from stream deposits. If the soil is made predominantly of fine particles, it could erode without lag gravels accumulating on the surface.

In any of the cases discussed above, if erosion is occurring, a depositional delta of fine particles should be visible somewhere nearby, either downstream or downwind. Deposits of fines may show up in small terraces—about 4 inches (100 millimeters) high—that accumulate behind plant litter or grass clumps, or as small deltas in low-lying areas where water slows. Depending on the slope and water velocity, these deltas may be several feet (a meter) to several yards (meters) away from the area that lost the fines.

When the surface litter is removed, fine particles in the soil are exposed to the impact of raindrops and to drying cycles between rains. Raindrop dispersion crusts will form within 0.04 to 0.08 inch (a millimeter or two) of the surface. These crusts may become weak to moderately strong. Sometimes this crust will have the horizontal platy structure that forms with compaction from foot traffic. If crusts form, the soil becomes less porous and less rain infiltrates. Precipitation and snowmelt increasingly flow overland, producing the surface waterflow that leads to particle transport and erosion.

3.1.3a Visual Clues for Evaluating Erosion

Erosion is caused by the impact of raindrops on bare soil, by the force of running water on the soil surface, by wind, and by rodent activity. Erosion is a natural process that leaves its signs across the landscape. Erosion from unnatural processes, however, often moves more soil more quickly than the erosion that occurs naturally. Erosion from unnatural processes produces significant impacts that require treatment. Both types of erosion are influenced by climate, soil type, slope, and vegetation type. Loam and silt loam soils are more erodible than clay or sandy soils. However, sandy granitic soils are highly erodible. Steep slopes are more erodible than gentle slopes. And well-vegetated slopes, especially those with a variety of root forms and aboveground biomass, are less erodible than areas with sparser vegetation.

Plant cover, surface debris, and biological crusts stabilize the soil. Bare soil between plants is the most susceptible to erosion. Soil compaction allows increased runoff. Trails that are poorly located or maintained funnel water into erosion channels (figure 3–20a). Sloped campsites lose soil in a downhill flow. Additional factors contributing to erosion include soil surface stability, soil aggregate stability, water infiltration, and organic matter content, all of which can be evaluated in comparison with suitable reference sites. Heavy grazing or weed establishment increases the risk of erosion.

Figure 3–20a—Sheep driveways established in the 1880s became the Forest Service trail system in the high country of many wilderness areas. Because this former driveway was located on the fall line, running water continues to widen and erode this trail in the Alpine Lakes Wilderness, WA.

Clues for surface erosion and degraded soil condition at the impacted site relative to the reference sites include:

- Bare soil—Unless the soil has been recently disturbed (by a burrowing animal or fallen tree, for instance), the soil should have a protective biotic crust, a thin layer of organic duff, or an armoring layer of gravel or stones.
- Lag gravels or plants or rocks on "pedestals"—If the surface has many more gravels or stones than the upper horizons in the soil profile, the fine soil may have been eroded away, leaving the heavier rocks to "lag" behind (see figure 3–19). If the process is very slow, as it is in the desert, the rocks may have a dark, oxidized patina, indicating slow erosion rates. If the soil is actively moving away from the local area because of raindrop impacts, soil protected under bits of wood or rocks may form pedestals (small, uneroded columns of soil with a protective cap). This indicates a more rapid, possibly unnatural process.
- Exposed roots—If soil has moved since a tree or shrub grew roots into the soil, the exposed roots will show the old soil levels (figure 3–20b).

Figure 3–20b—Exposed roots show the old soil level.

- Terracettes—Level benches of soil deposited behind obstacles are an indication that erosion removed the surrounding soil (figure 3–21).

Figure 3–21—Vegetation growing on level benches of soil deposited behind rocks is evidence of past erosion.

- Waterflow patterns—An increase in the number, size, and connectivity of waterflow patterns (rills) between plants is an indication of erosion.
- Soil deposition at slope changes—Where a steep slope flattens into a shallow slope, the speed of waterflow decreases and sediments will deposit, forming a fan if soil is being eroded.
- Changes in thickness of topsoil—Thick topsoils in areas of deposition (swales or lower on slopes) mean soil has been lost higher up the slope (on the shoulder of the slope or midslope).
- Exposure of subsoil at the surface—Subsoils are marked by higher clay content, redder color, or larger blocky or massive soil structure. These subsoils may form small cliffs. The softer surface soils and deeper subsoils weather away, leaving the subsoil protruding prominently.
- Rills, headcutting (movement of a gully upslope by progressive erosion), and/or downcutting (deepening) in gullies—Rills (only about 0.1 inch or a few millimeters deep) are formed by moving water that has enough energy to carry sediment.
- Reduced plant vigor—As topsoil is removed, less moisture and nutrients are available for plant growth and plants are smaller.
- Long, unsheltered, smooth soil surfaces—Wide expanses of fines in playas or deltas, with silt accumulations behind rocks or shrubs in gullies are potential indicators of windblown sites.
- Exposed, erosive subsoil under a resistant cap—Look for evidence of rodents burrowing into terraces or pedestals, further eating away at the remaining soil. Pedestal faces relate to trails or old erosion patterns, not to natural landforms and stream hydrology (U.S. Department of Agriculture Natural Resources Conservation Service, Soil Quality Institute 2001c).
- Evidence of wind erosion—Wind-scoured areas between plants, a drifted or rippled soil surface, biological crusts buried by blown soil, loose sand on physical crusts, and soil or leaf litter accumulating on the leeward side of plants and obstacles are signs of wind erosion (U.S. Department of Agriculture Natural Resources Conservation Service, Soil Quality Institute 2001d).

Table 3–1 provides a summary of soil indicators you might consider during your soil assessment.

Table 3–1 —Indicators of soil quality and their relationship to soil health. (Adapted from *Guidelines for Soil Quality Assessment in Conservation Planning*, U.S. Department of Agriculture Natural Resources Conservation Service, Soil Quality Institute 2001a)

Indicator	Influence on soil function
Soil organic matter (SOM)	Improves fertility, soil structure, soil stability, nutrient retention, soil erosion, and available water capacity, but must be renewed by continued plant growth.
Physical	
Soil structure	Good soil structure and aggregation increases water infiltration, retention of water and nutrients, and habitat for microbes, while decreasing erosion. Aggregates are destroyed by traffic and plant removal.
Depth of soil and rooting	Deeper soil increases site potential (annual weeds vs. forbs vs. shrubs vs. trees). Soil compaction, plow pan, and impermeable rock layers reduce growth.
Infiltration and bulk density	Soil structure increases and bulk density decreases water movement, soil porosity, and soil workability (soil tilth).
Chemical	
pH	Soil reaction (pH) has wide ranging influences on biological and nutrient availability, and on plant species that are appropriate for restoration.
Electrical conductivity (EC)	EC is a measure of salinity, which influences plant growth, microbial activity, and the formation of salt crusts.
Cation exchange capacity (CEC)	The capacity of soil to hold nutrients for plant use. Specifically, CEC is the amount of negative charges on clay and humus that are available to hold positively charged ions.
Extractable nitrogen (N), phosphorus (P), and potassium (K)	These plant nutrients are essential for growth. Excess nutrients may degrade local watersheds.
Biological	
Microbial biomass carbon (C) and nitrogen (N)	Microbes catalyze the decomposition of organic matter to release nutrients for continued plant growth. The microbial biomass provides a repository for carbon and nitrogen, creating a long-term nitrogen supply.
Potentially mineralizable nitrogen (PMN)	An operational pool made up of microbial plant litter and animal scat that provides a medium-term nitrogen supply. Soils with low PMN have short-term and often insufficient supplies of nitrogen.
Soil respiration	Respiration indicates microbial activity, which relates to nutrient cycling, organic residue formation, soil aggregation, root health, and symbiotic associations.

On the undisturbed site, you can expect to see several types of evidence of soil stability if erosion processes are minimal (except in areas such as naturally occurring badlands or sites at high elevation). Evidences of stability include an accumulated layer of plant litter and powdery organics in the O horizon, formation of weathering patinas or dark stains on surface rocks, aggregated soils, and a lack of surface erosion patterns, including pedestals or deltas formed by transported particles. Biological crusts formed by bacteria, fungi, lichens, algae and mosses that tolerate drying are another desirable feature of stable soil. Crusts create a natural protective layer at the ground surface that resists erosion.

3.1.3b Evaluating Physical Soil Crusts

Soil surfaces often develop a structured surface layer called a soil crust. A physical crust is a thin, compressed layer of soil minerals that indicates a loss of soil aggregate structure, decreased water infiltration, and increased runoff. Physical crusts are commonly formed by raindrop splash, erosion, and intense fire. Physical soil crusts support very little biological activity.

A physical crust is likely to be found on a site that has very little organic material where the soil aggregates are disintegrating into single-grain particles. A physical crust may form after a restoration treatment once the soil has been decompacted. The combination of a smooth surface and the lack of organic matter provide conditions for the formation of physical crusts. Physical crusts reform quickly after disturbance as raindrops disperse the fines and settle them into a thin, dense layer. Drying allows the crust to harden. Many wilderness campsites or social trails are firmly compacted, but they would not be said to have a crust because the surface is not denser or more structured than the underlying soil profile.

Excess salt in the soil can promote a chemically induced physical crust. Salt crusts appear as white areas that coat the existing soil surface. Some physical crusts formed by the evaporation of small pools of water are harmless. These have been observed in granitic areas where a pool of rain has evaporated and left a frost-like ring of salt crystals on pine needles on the forest floor. Lowland areas and arid environments can generate more serious salt accumulations, which are visible as some pattern of light-colored evaporates (salt crystals) from groundwater or rainwater. The salt may be left in lines that form on the sides of ponded areas, at the top of mounds of soil, or as rings around seeps. The measurement of salinity will be covered in section 3.2.2, *Soil Nutrients, pH, and Salts.*

To evaluate a site for physical crusts, lift the soil surface with the tip of a knife and look for cohesive layers parallel to the soil surface. Physical crusts (figure 3–22) will have no evidence of organisms, such as dangling plant roots or cyanobacteria holding the layers together. Fragments of a physical crust will fall apart (slake) when they are placed in water. This test is used to distinguish them from cemented layers that would occur in drier environments. Platy structures parallel to the soil surface that disintegrate in water are the clues to identifying physical crusts. Well-aggregated soils break into round crumb structures rather than platy structures.

Figure 3–22—Physical crusts, which often form on disturbed soils, will hinder vegetative recovery. Photo courtesy of the U.S. Department of Agriculture Natural Resources Conservation Service.

The formation of a physical crust will deter a site's recovery. First, crusts indicate a soil low in organic matter. Raindrops disperse the soil into particles that clog pores in the soil, impeding plant growth. Second, the crust's low infiltration rate means rainwater and snowmelt will not seep down into a soil, but will run off the surface as sheet flow. Third, crusts suggest that salts or too many fine particles may cause drainage or nutrient problems. Tillage can disrupt crust, but organic material must be amended into the soil to keep the crust from reforming during the next rain. Foot traffic can disrupt a surface crust, causing it to disappear, but it will reform readily.

3.1.3c Evaluating Biological Soil Crusts

Some crusts are beneficial. A biological or microbiotic soil crust is comprised of bacteria, fungi, algae, lichen, mosses, or liverworts that form at the soil surface, stabilizing the soil, improving water infiltration, and increasing the flow of water and nutrients to plants. Biological crusts have an uneven surface and pore spaces that increase infiltration, reducing runoff. Although biological crusts can enhance seed germination, depending on the type of crust and plant species involved, in very hot deserts biological crusts may inhibit germination. Unlike physical crusts, biological crusts have high levels of organic matter, typically are the colors of the organisms that form them, and are not prone to slaking in water.

Although biological crusts do not form in all soil types and vegetative communities, the presence or absence of a biological crust is critically important in some environments. Biological soil crusts are common in arid and semiarid regions and in alpine areas with little litter accumulation. Crusts also have been studied in native prairies, in the sandy soils of Glacier Bay, AK, and even in the Antarctic.

Biological or microbiotic crusts also are referred to as cryptogamic, cryptobiotic, and microphytic crusts, depending on the type of organisms present. Biological crusts form when living organisms or their byproducts create a surface crust of soil particles bound by organic materials (figure 3–23). In disturbed sites, look for biological soil crusts in fenced areas, lightly used areas under shrubs, or between closely spaced rocks.

Figure 3–23—This electron micrograph shows soil particles bound by the sheaths of micro-organisms found in biological crusts. Photo courtesy of the U.S. Department of Agriculture Natural Resources Conservation Service.

Biological crusts vary tremendously in thickness, texture, color, and in the species that form them. For example, the cyanobacteria that are dominant in arid soils form pinnacles up to 6 inches (150 millimeters) high (figures 3–24a and 24b). Other soils may have moss or lichen growing on the surface (U.S. Department of Agriculture Natural Resources Conservation Service, Soil Quality Institute 1997 and 2001b). A common pattern is for a moss or lichen crust to form terracettes, benches 2 to 4 inches (50 to 100 millimeters) wide that are flatter than the slope angle. Because the terracettes are stable when wet, they trap sediment and persist during rains.

Figures 3–24a and 24b—Intact biological soil crusts (top) provide many ecological benefits. They stabilize the soil, increase nutrient flow to plants, and provide safe sites for seeds to germinate (bottom).

If a biological soil crust has been broken, compressed, or removed because of grazing pressure or compaction (figure 3–25), the soil is susceptible to wind and water erosion, as well as the formation of a physical crust. In addition, the biological crust loses some of its ability to fix nitrogen. If biological crusts are buried by blowing sand, they will die. Fire also can kill organisms that form biological crusts. For more information on biological soil crusts, visit the U.S. Geological Survey Canyonlands Research Station's Web site at *http://www.soilcrust.org.*

Figure 3–25—Biological soil crusts are easily damaged.

Rocks or large plants often serve as microhabitats, creating safe sites for biological crusts and other plants to grow around or under. In evaluating the reference site, note such features and include them in the restoration prescription, if feasible. The rocks provide shelter, additional moisture from runoff, shade, heat, and protection from trampling.

3.1.4 Soil-Water Relations

A soil's ability to provide water for plant growth is influenced by three factors:

- Infiltration of moisture
- Water-holding capacity
- Overall size of the rooting volume

3.1.4a Soil Texture and Pore Size

Infiltration is governed by the size of pores in the soil. Healthy soils are about 50-percent open pore space. That space is divided into many individual pores of various sizes. The distribution of large and small pores determines how well the soil soaks up moisture and holds it for plant growth. Large, continuous pores allow rainwater or snowmelt to infiltrate into the soil. These pores are created by burrowing insects and worms, old root channels, and spaces between large soil aggregates. Small pores, on the other hand, retain water that plants can use later. The small pores are mainly spaces between clay and silt particles.

Infiltration can be improved by the formation of soil aggregates, which create voids between adjacent clusters of soil particles. Macroaggregates are 0.01- to 0.4-inch (0.25- to 10-millimeter) groups of soil particles glued together by soil organic materials and fungal hyphae. Spaces between aggregate clusters are large enough for water to flow through. Gravity can pull water through pores that are as large as about 0.1 inch (several millimeters) or as small as about 0.0003 inch (7 micrometers)—10 times thinner than a human hair. When water falls on degraded sites, it often does not infiltrate. Instead, the water begins to flow overland, generating erosion and transporting sediment.

3.1.4b Available Water-Holding Capacity

After water has infiltrated, the soil's ability to hold water until plants use it is called the available water-holding capacity (AWC). This value is estimated from the maximum soil water capacity after a rain minus the residual water plants cannot withdraw from the soil. The maximum soil water capacity is called the field capacity, defined as the water content after the soil is drained by gravity after a rain. This amount is estimated by applying suction with a pressure of about –0.0142 British thermal units per pound (–33 joules per kilogram) of soil. This negative pressure used to be described as "–⅓ bar" (1 bar is normal atmospheric pressure). Residual water left when crop plants can no longer remove moisture (wilting point) is set at –0.6449 British thermal unit per pound (–1,500 joules per kilogram, formerly "–15 bar"). Some wildland plants can withdraw water to pressures of –2.1496 British thermal units per pound (–5,000 joules per kilogram, formerly –50 bar).

While compost, soil aggregates, root channels, and animal burrows help increase infiltration of moisture into the soil, they have less effect on the water retained during droughty periods. Clay content is the primary soil characteristic that influences the amount of water retained in the soil during drier conditions. In such conditions, water is estimated to be held in pores 0.00001 inch (0.16 micrometer) or smaller (based on a hypothetical circular pore). Clay particles are 0.0001 inch (2 micrometers) or smaller. The spaces between these particles create pores of the appropriate size to store water that can be withdrawn by a plant during dry conditions. Often, wildland plants can withdraw water held in pores smaller than 0.000002 inch (0.05 micrometer). Because only clay-sized particles provide such small pores, little else in the soil can provide this kind of long-term moisture retention.

Generally, if soil AWC was less than 10 percent, moisture retention was increased with organic amendment using yard waste components (Curtis and Claassen 2005). If the soil's AWC was greater than 10 percent, net water availability remained about the same after amendment, although infiltration increased. If organic amendments are near the surface, however, they may dry out by evaporation before plants can access their stored water later in the year. Moisture deep in the profile is more likely to be available to plants during dry times. Another way to increase moisture availability is to increase rooting volume by decompacting the soil.

The distribution of pore sizes controls water relations in soils. The pore structure tends to be more open in the upper horizons compared to the lower horizons. This distribution occurs because organic materials that accumulate in the A horizon increase particle aggregation. The smaller pores in the clay-rich B horizon pull harder on the soil moisture, drawing it deep into the soil profile. When fine-textured substrates are on top of coarse-textured substrates (small pores over large pores), soil water may not percolate deeply into the soil. It may remain near the surface where it can evaporate or run off.

An example of this situation occurs in the Enchantment Lakes Basin of the Alpine Lakes Wilderness in Washington where fine-textured ash soils overlie coarser mixtures of ash and glacial gravels (Juelson 2001). Water is retained in the upper horizons, especially when the impacts of foot traffic cause soils to lose their structure. A potential treatment would be to mix soils in at least some of the areas to the rooting depth, increasing the amount of water deep in the soil profile.

3.1.4c Determining Water-Holding Capacity

Soils can be evaluated for plant available water content by measuring the water at field capacity, –0.0142 British thermal units per pound (–33 joules per kilogram), minus the water content at some drier condition, usually –0.6449 British thermal units per pound (–1,500 joules per kilogram). This measurement, called *third bar minus 15 bar water content*, often is available through commercial soil analysis labs. The problem with sending in a sieved soil sample for lab analysis is that the process of sieving the sample to get the rocks out tends to fluff up the soil and increase its field-capacity water content. Also, the actual water content of the soil at the project site will be decreased if the substrate is compacted there. The wilting-point water content is determined mainly by the sample's clay content. Sieving or processing the sample will not affect the wilting-point water content.

Soil additives that are intended to increase moisture availability must be evaluated with respect to the water demands of plants. Amendments that supply temporary or near-surface water, but do not improve general infiltration or increase the volume of water stored for droughty periods will not sustain plant communities. Soil amendments will be discussed in more detail in section 3.2, *Making Site Amendments Based on Site Evaluations.*

3.1.5 Determining Soil Texture

Soil particle sizes can be estimated in the field by hand or determined in the lab by several methods. Soil particles are categorized into three groups (sand, silt, and clay) that occur in various combinations. Each type of particle lends a distinct feel to the soil. Sand has visible, coarse grains, feels gritty, and does not hold together when compressed in your fist. Silt particles are slightly larger than clay particles and will feel like talcum powder when you rub moist silt between your fingers. Individual clay particles are not visible with the naked eye. When moist, clay will hold together when compressed in your fist (figure 3–26). Wet clay particles tend to stain the fingers, even when the soil has been wiped off. When dry, clay may be too hard for a shovel to penetrate.

Figure 3–26—The hand test is a reasonably reliable way to determine soil type. An uncompressed soil sample is squeezed in the palm of the hand.

A soil with equal influences (not volumes) of clay, silt, and sand is called a loam. Clay has more surface area, giving it more influence than its percentage of the soil's volume would indicate. Loam has the benefits of all particle types. A native soil also may have gravel (smaller than 3 inches or 75 millimeters), cobbles (smaller than 10 inches or 250 millimeters), stones or boulders (larger than 24 inches or 600 millimeters) mixed in. The type of loam depends on the ratio of clay, silt, and sand. The different types of loam can be recognized in the field using techniques described in the following box.

Field Tests To Determine Types of Loam

Refer to figure 1–15 for the percentages of clay, silt, and sand in the different types of loam.

Sandy loam—Grains of sand can be seen readily. The damp soil will not form casts (the shape the soil forms when pressed inside the fingers and palm), but the wet soil forms slightly stable casts. A ribbon will not form when the soil is rolled between the fingers. The soil feels gritty between thumb and forefinger.

Loam—A few grains of sand can be seen. Moist casts will form, but are easy to break apart. Wet casts are moderately stable. A ribbon will not form when the soil is rolled between the fingers.

Silt loam—Only a very few grains of sand can be seen. Damp casts form and resist breaking apart somewhat. Wet casts are stable. When the soil is rolled between the fingers, a thick ribbon will form, but will break apart.

Clay loam—No grains of sand can be seen. Damp casts are hard and stable. Wet casts are stable. When the soil is rolled between the fingers, wet soil will form a thin ribbon, but the ribbon will break under the pull of gravity (unlike true clay).

A soil's texture has great influence on its potential to hold water and nutrients and to diffuse air for root growth. If plants require irrigation, the soil type makes a huge difference in the frequency of watering and in the amount of water that will be needed. Clay particles have the most surface area for water films. They attract the most nutrients because the clay minerals have a negative charge that holds positively charged nutrients. Because of the small pore sizes, a perpetually saturated clay soil will prevent most plant roots from getting enough oxygen. Organic matter, such as the cellulose and lignin found in decaying plant materials, and humified soil organic matter hold more water and nutrients than clay. Sand drains water and leaches nutrients away more quickly than any other particle type. Loam soils provide a balance of water, nutrients, and oxygen.

If soil needs to be added to a restoration site, match the soil texture to that on the reference site. Native plants often are adapted to specific soil conditions, which must be approximated in the project design.

3.1.6 Evaluating Soil Compaction

Compaction reduces the pore space between soil particles, affecting the ability of water, nutrients, and air to penetrate the soil. Compaction impairs root growth and alters or eliminates the proper functions of soil micro-organisms. Dry soils offer more resistance to compaction than wet soils. Finer textured soils are compacted more easily than coarser soils. Volcanic ash is prone to compaction, because it has fine particles with a uniform particle distribution. Decomposed granite is prone to compaction because it has coarse particle size (and low pore volume) and a high silt content. Silts are less charged and sticky than clays, so they can plug the pores between the large grains. Overland flows easily wash the silty and fine sand particles from the soil.

Soils with a well-developed structure, high aggregate stability, or ample leaf litter are less susceptible to compaction. In compacted soils, films of water bridge pores and block gas flow, leading to anaerobic conditions (lack of oxygen) that cause nitrogen to be lost through denitrification. Interestingly, some compaction increases the water-holding capacity of sandy soils.

Compaction from human use or grazing can extend 6 inches (150 millimeters) deep, sometimes deeper. Compaction from vehicles on a well-traveled road may be 2 feet (600 millimeters) deep or deeper. Deep layers of compaction interfere with the percolation of water to deep root zones, favoring more shallowly rooted plants, such as annual grasses.

Compaction is common at wilderness campsites, trails, or any other areas of concentrated recreational use. In areas with heavy snowfall, scarified restoration sites are likely to become recompacted under the mantle of snow, especially if the soil lacks ample organic material, mulch, and a mixture of particle sizes.

Compare the degree of soil compaction at the restoration site and at the reference site by using a shovel or a tent stake to pierce soil layers at each site. Compaction may be obvious if digging is more difficult at the impacted site. Often, a compacted loam will become compressed into platy layers that are easily recognized once a shovelful of soil has been exposed.

Comparing plant root penetration is also useful; if roots only penetrate to a certain depth at the impacted site before spreading out, compaction should be suspected. Roots also may appear to be restricted, flattened, turned, horizontal, or stubby at the impacted site relative to the reference site (U.S. Department of Agriculture Natural Resources Conservation Service, Soil Quality Institute 2001f).

Sometimes a layer of compaction forms well below the soil surface. For example, in an agricultural setting, a "plow pan" layer may form just below the reach of the plow. Water and roots may not be able to penetrate this layer.

3.1.6a Measuring Bulk Density

A more scientific assessment of compaction can be made by using a soil penetrometer or by measuring the soil's bulk density as part of a soil test. Bulk density is calculated by dividing the weight of the soil by its volume. Each soil texture has a bulk density at which root penetration may become restricted (table 3–2). Gravels and cobbles may increase bulk density weights even though the fine soils are not compacted. Be sure the bulk density samples are fairly uniform soil volumes without rocks.

Table 3–2—Bulk densities at which root growth becomes restricted. (Excerpted from *Rangeland Soil Quality—Compaction*, U.S. Department of Agriculture Natural Resources Conservation Service, Soil Quality Institute 2001e)

Texture	Root-restricting bulk density oz/cubic in (gm/cubic cm)
Coarse, medium, and fine sand; and loamy sand, other than loamy very fine sand	3.12 (1.80)
Very fine sand, loamy very fine sand	3.07 (1.77)
Sandy loam	3.03 (1.75)
Loam, sandy clay loam	2.95 (1.70)
Clay loam	2.95 (1.70)
Sandy clay	2.77 (1.60)
Silt, silt loam	2.69 (1.55)
Silty clay loam	2.60 (1.50)
Silty clay	2.51 (1.45)
Clay	2.43 (1.40)

If the restoration site is compacted, breaking up the compaction will be critical to plant establishment. Breaking up compaction in the subsoil often helps reestablish soil micro-organisms, but can reduce the numbers of burrowing organisms, such as earthworms.

3.1.6b Interpreting Bulk Density

When using bulk density numbers, remember that these values only represent rooting restrictions in a massive soil (one that has no natural cleavage planes; the soil is uniformly dense). Massive soils occur in freshly deposited materials or after tillage and excavation. Soil-forming processes create organic films and channels, making the bulk density and structure of soil uneven. Bulk density values are difficult to apply to well-developed soils in which roots follow old root channels or fractures between rocks or soil aggregates, rather than penetrating directly through uniform soil masses. Roots may penetrate dense material easily if the soil has well-developed cracks along soil structures, as in the case of a very dense, clayey subsoil that has its structure intact. After being tilled and disrupted, the same soil may settle into a massive structure that plant roots cannot penetrate.

In summary, bulk density data must be interpreted with regard to soil structure. When plant roots grow down to restricting layers and spread laterally or become stunted, the soil depth or compaction is limiting root growth. When roots find fissures and cracks and continue growing downward, bulk density is of secondary importance.

3.1.6c Evaluating Water Infiltration

Infiltration is the rate at which water soaks into the soil. Infiltration determines the amount of water that will be in the soil for plants, rather than being lost as overland flow. Infiltration is impaired on compacted soils or soils with physical crusts. Sometimes, deep layers of dry needles or duff or areas with dense root mats can keep water from soaking into the soil before it wicks down the slope. The infiltration rate is highest when soils are dry, well aggregated, and unfrozen. Soils with a high percentage of plant cover, root mass, and organic content have higher infiltration rates.

Other natural functions that affect infiltration include soil texture, clay crusts, mineral content, soil horizons, soil depth, organic matter, soil biota, soil structure and aggregation, biological crusts, and the presence of a water-repellent layer (such as from the oils of waxy vegetation). Some of these factors can be managed as part of a site prescription.

Infiltration is measured by how fast the water enters the soil (in inches or millimeters per hour). To measure the infiltration rate, a cylinder is partially forced into the upper layer of the soil, sealing the cylinder's edges. Water is added to a depth of about 1 inch (25.4 millimeters) in the cylinder. The rate of infiltration is timed.

Standing water can run quickly down burrows, root channels or cracks, indicating a high potential for infiltration. However, natural rainfall leaves a thinner layer of water across the soil, which will flow across and down the slope. A standing-water infiltration test can give overly high readings on soils with burrowing activity, old root channels, or shrinkage cracks.

Did You Know?

Infiltration rate is a measure of how fast water enters the soil. Water entering too slowly may lead to ponding on level fields or to erosion from surface runoff on sloping fields.

Procedure for Infiltration Test

Excerpted from: *Soil Quality Test Kit Guide*, U.S. Department of Agriculture Natural Resources Conservation Service, Soil Quality Institute 1999

Materials Needed

6-inch- (152-millimeter-) diameter ring
Plastic wrap
500-milliliter- (17-ounce-) plastic bottle or graduated cylinder
Distilled water
Stopwatch or timer
Block of wood
Hand sledge

Test Steps

Step 1—Drive the ring into the soil.

- Clear the sampling area of surface residue and other materials. If the site is covered with vegetation, trim the vegetation as close to the soil surface as possible.
- Using the hand sledge and a block of wood, drive the 6-inch- (about 152-millimeter-) diameter ring (beveled edge down) to a depth of 3 inches (about 76 millimeters, line marked on outside of ring).

Step 2—Firm the soil.

- With the 6-inch- (about 152-millimeter-) ring in place, use your finger to gently firm the soil surface (only around the inside edges of the ring) to prevent seepage there. Minimize disturbance to the soil surface inside the ring.

Step 3—Line the ring with plastic wrap.

- Line the soil surface inside the ring with a sheet of plastic wrap, completely covering the soil and ring. This procedure prevents disturbing the soil surface when water is added.

Step 4—Add water.

- Fill the plastic bottle or graduated cylinder with distilled water to the 15-ounce (444-milliliter) mark.
- Pour 1 inch (25.4 millimeters) of water into the ring.

Step 5—Remove the plastic wrap and record the time.

- Gently pull the plastic wrap out, leaving the water in the ring. Note the time.
- Record the time (in minutes) it takes for the 1 inch (25.4 millimeters) of water to infiltrate the soil. Stop timing when the soil surface is just glistening.
- If the soil surface is uneven inside the ring, count the time until half of the surface is exposed and just glistening.

Step 6—Repeat the infiltration test.

- In the same ring, repeat steps 3, 4, and 5. Record the number of minutes for water to infiltrate the second time.

The moisture content of the soil will affect the rate of infiltration. Two infiltration tests are usually performed if the soil is dry. The first inch of water wets the soil, and the second inch gives a better estimate of the infiltration rate.

3.2 Making Site Amendments Based on Site Evaluations

Soil treatments will improve the soil conditions so they came as close as possible to the reference condition. Prescriptions address needs for correcting soil organic matter, nutrient balance, and biota. Soil organic matter is that fraction of the soil composed of anything that once lived. Soil compaction is broken up, and missing soil horizons are rebuilt as much as feasible. Invasive species concerns also affect the types of soil treatment that might be needed.

3.2.1 Soil Organic Matter and Mulch

Mulch can form a protective layer over the soil, blocking the impact of raindrops and keeping the soil cooler and moister during the summer and warmer during the winter. Because of the large accumulation of litter in many undisturbed systems, organic horizons can be harvested from existing forest floors (by hand raking, for instance). Litter can be spread on the impacted site to speed regeneration. Litter may have to be harvested from a different location several years later to continue helping the treated site recover. For comparison, about 2,000 pounds per acre of weed-free straw (about 1 megagram per hectare) are applied for erosion control at construction sites.

Commercial composts can also be used. Regulations on compost production should keep viable weed seeds from contaminating the site, but problems may occur. For instance, the edges of compost piles may harbor weed seeds; compost can be contaminated in trucks during transport; and weeds may blow in or grow on the compost pile after it has finished actively composting.

Many commercial composts are screened to create a uniform product. While screening produces a uniform, fine material, the material is less resistant to erosion. Coarse, unscreened composts with shreds of wood around 4 to 6 inches (100 to 150 millimeters) long are more resistant to erosion. Wood chips are not as good as shreds of wood; the chips can move because they are not long enough to intermesh. Despite these problems, composts are excellent ways to build mulches and soil organic matter in general. Although nutrient release (especially nitrogen) varies initially in compost and organic amendments, they do increasingly well in subsequent seasons, even if they are a little hot (releasing nutrients too quickly) or cold (releasing nutrients too slowly) during the first year.

A thin layer of straw is a cost-effective way of providing a minimal level of erosion protection. If native grass hay can be used, the seed heads can help provide some seeding. Thicker layers (¼ to ¾ inch, or 6 to 19 millimeters) of straw help retain soil warmth and moisture but may delay seed germination in cooler climates.

3.2.2 Soil Nutrients, pH, and Salts

Nutrients available for plants are derived from a number of sources, including organic material, atmospheric cycles, and the weathering of bedrock. Soil tests are designed to extract an amount of nutrient that is proportional to the "plant available" nutrient pools in the soil that are accessed by the plant. Each general type of nutrient is extracted by a separate test. The test for each type of nutrient must be interpreted differently, often with regard for the type of geological material at the site. Soil test data must be interpreted appropriately based on the type of sampling, soil type, and test method. Furthermore, plant growth is constrained by the most limiting soil condition, so an adequate level of one nutrient is no guarantee that all other conditions are adequate.

Comprehensive soil tests cost between $25 and more than $100 per sample. They can be used to survey a site initially, or they can be used to track the effectiveness of an amendment. Often, their cost is inexpensive compared to the overall project costs.

Comparative soil testing or, in some cases, plant tissue analysis, is the only way to determine whether the soil is deficient in nutrients. Soil nutrients or plant tissue from the restoration site are compared to samples from an undamaged control site. A soil lab will recommend how to correct soil deficiencies using fertilizers or other soil amendments. Most soil labs primarily service the agricultural industry, so test results are often geared toward remedying deficiencies of agricultural nutrients. Native plants tend to have much lower nutrient requirements. The comparative test is important because it allows the restorationist to compare the difference between undisturbed soils and soils from the impacted site. Even if nutrient levels appear to be low by agricultural standards, if plants are surviving and reproducing on the reference site, the nutrient level there can be assumed adequate for the impacted site.

To locate a soil lab, consult with your agency soil scientist or call the land grant university that operates extension services in your State. These universities have soil labs and soil chemists who work directly with the public and with agencies. Specialized soil labs also can test for biological properties of soils, such as microbial respiration or the numbers of soil micro-organisms. Agricultural labs can be used for many important tests, but be sure to interpret the results with respect to wildland sites, not agricultural sites. The revegetated or native reference site provides the comparison that is the most representative for your project conditions.

Your soil scientist and soil lab can tell you how to collect the sample. Having four replicates of soil samples provides more reliable results, and can show how much variation there is in the site. Alternatively, the samples can be mixed together (composited), which saves money, but will not show areas in the site with high or low nutrient conditions. The following example shows how soils are generally sampled.

1. View the whole area and divide it into parts with similar characteristics for sampling (landform, usage, plant type). For example, you may want to evaluate a slope in contrast to a basin or flood plain, or north- versus south-facing slopes. For each contrasting area of the site, try to identify a similar "revegetated reference" area that supports acceptable cover and diversity. Three or four replicate samples will show whether the measured values are consistent, but a single sample composited (mixed equally) from several samples also can indicate a general condition.
2. If surface horizons of organics, litter, mulch, or biotic crusts are important at the site, delineate a known area (often 9.8 or 19.6 inches [250 or 500 millimeters] square) and harvest the organic layer. Organic litter can be measured by weight or thickness and used in a specification for regenerating the impacted site. The crust, if present, can be laid aside and reapplied after disturbance. Collecting from a defined area allows one to specify the weight or volume of material needed for the impacted site.
3. Dig the pit to the maximum rooting depth. This allows you to tell whether the pit will be successful (no buried boulders) and to see the most general aspects of the soil before details are evaluated. Hand-excavated pits often are about 11.8 inches (300 millimeters) square. When the pit has been dug, clean the walls that will be sampled. Afterward, sample the deepest horizon first.

   This horizon usually has the least organic carbon, so it is important not to contaminate it with debris from the A horizon. Collect about 17 ounces (500 milliliters) of material and note the relative proportion of coarse fragments as a percentage of fine (smaller than 0.08 inch [2 millimeters]) soil material. Often, an estimate of the coarse fragments that are not put in the bag is combined with the sieved fractions (larger than 0.08 inch [2 millimeters] and smaller than 0.08 inch [2 millimeters]) from lab analysis. In this way the fine soil analysis for nutrients and water content can be prorated for soil volumes with high rock content.

4. Next, successively sample higher horizons from the bottom up, so that nutrient-rich higher horizons are not sloughed down on lower horizons. Commonly, a deepest rooting horizon is sampled (often the C horizon) and a surface horizon (often the A horizon) with maximum nutrient content is sampled. This often works out to be samples from 0 to 3.9 inches (0 to 100 millimeters), 7.9 to 11.8 inches (200 to 300 millimeters), and 19.7 to 23.6 inches (500 to 600 millimeters).
5. Dry the samples (within 24 hours if possible) by spreading them out to air dry or in an oven overnight. Avoid high heat (temperatures above 113 degrees Fahrenheit, 45 degrees Celsius).
6. Ship the samples immediately in properly labeled sample bags or boxes. Avoid using generic labels, such as "Soil A," because the lab (or your database) may have many such samples. If plant samples are collected, it is important to know the part of plant where the samples were taken. When comparing plants on the reference site and those on the impacted site, sample similar plants, and similar tissues on the plants.
7. Additional information that could help you interpret sample data later on includes the previous type of vegetation on the site, the species to be grown there, whether the soil was hard or loose, topsoil depth, the relative amount of roots in the soil (no roots, few roots, many roots), the vigor of existing vegetation, leaf color (dark green, light green, yellow or brown spots on upper or lower leaves), and previous soil treatments. Often, an agriculturally oriented lab will not be able to provide a coherent interpretation of the analysis results for a wildland site. You should be able to interpret the results by comparing samples from the reference site to samples from the impacted site.
8. Once you have the test results, you might use amendments or fertilizers to increase nutrients to low, but adequate, thresholds. When working with native plant communities, more is not better. Be sure the interpretations are appropriate for wildland plants, not agricultural or horticultural plants. See section 3.2.3d, *Evaluating Soil Nutrients and Chemical Conditions*.

Subsequent tests should be done at the same lab so the analyses are consistent. For monitoring, take soil samples at the same time of year under similar moisture conditions, if possible.

A sample site assessment field form can be found in appendix E, *Forms*. This form can be modified to meet your needs.

3.2.3 Rebuilding Damaged Soils

Ideally, the restorationist will attempt to re-create the structure and function of the altered soil layers. The soil assessment evaluates soil function by identifying attributes or properties that have been altered, or that would impair reestablishment of the desired plant community. For each attribute that has been damaged, the restorationist identifies a method to ameliorate the damage. The two most important issues commonly limiting plant growth on drastically disturbed sites are water availability (based on slope structural stability, infiltration, and rooting volume) and long-term nitrogen release (Claassen 2002). Nutrients other than nitrogen can be added easily by fertilizer amendments, if they are needed.

3.2.3a Scarification

In some instances, the topsoil layer is largely intact, but its function has been impaired by compaction. Thoroughly loosening the soil may reintroduce the macropores that allow water and air to circulate. This process, called scarification, is particularly helpful in making sure that germinating seedlings have enough water available during their first weeks of establishment.

Tilling usually is not appropriate, because it mixes and pulverizes the soil, destroying soil aggregates. In some soils the rotating tines may create a tillage compaction layer. If organic matter has accumulated on the site, a priority may be to keep the topsoil layer on top where it can serve its proper function rather than tilling it into deeper soil layers. Most wilderness and backcountry sites are decompacted by breaking up the soil with a shovel or garden fork without mixing the C horizon into the organic layers.

Infiltration in a compacted soil may be improved with the incorporation of organic matter. A replacement mulch layer also may be a good idea. It is not entirely clear how important it is to keep the soil layers separate. Work by Dr. David Cole in the Eagle Cap Wilderness of Oregon (Cole and Spildie 2000) produced favorable results after various soil layers were mixed. Focus on patterns of water movement through the soil profile (no abrupt soil texture differences), accumulated organic matter on the surface (leave these valuable materials in place or replace them), and soil horizons (leave finer B horizon materials at depth and minimize damage to soil aggregates in the A horizon).

It may be necessary to crumble compacted soil by hand to break up compressed plates. The soil needs to be decompacted to the depth that plant roots need to reach (check the reference site for rooting depth). For highly compacted soils, a pick may be the tool of choice. Another tool to try in backcountry settings is the U-bar digger. This U-shaped tool has long tines at the base mounted to a crosspiece, with two long handles coming up the sides (figure 3–27). The operator steps on the crosspiece, grasps the handles, and rocks the tines back and forth to penetrate the soil. This works nicely to break up moderate compaction to just over a foot deep.

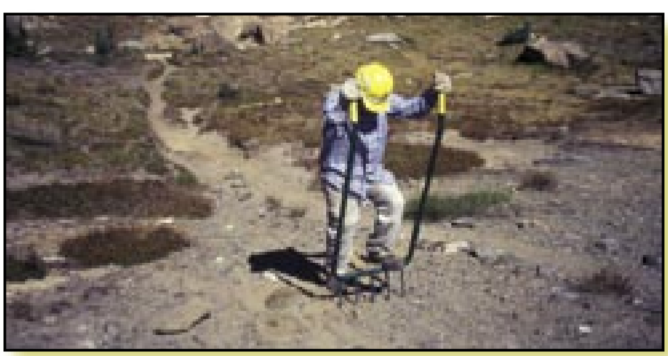


Figure 3–27—The U-bar digger is used to break up compacted soil.

The tool could be broken down for transport, but it is heavy. The tines need to be sheathed for safety if the tool is transported on stock. (See chapter 5, *Tools of the Trade and Other Resources*, for more information about acquiring this tool, a personal favorite of the author.)

Dr. Jayne Belnap cautions that desert soils may become more compacted after scarification, making matters worse (Belnap 2003). This may occur because fragile soil aggregates disintegrate when they are tilled. According to Belnap, it remains unclear when scarification is appropriate in a desert environment, so restorationists be warned! Find out what others have done in your area. Often, damaged soils must have organic matter mixed in to keep the soil open. Shredded wood from thinning projects could be used or harvested forest floor duff could be harvested and incorporated into the top 6 to 8 inches (150 to 200 millimeters) or so of soil. Olympic National Park uses Cocobrick, a product made from coconut fiber, to increase the organic content of soils.

3.2.3b Rebuilding Missing Layers of Soil

If the topsoil layer or deeper layers of soil are missing, as will be the case for eroded trails and excavated or sloping campsites, the task is to add one layer of soil at a time, if possible, being mindful of how limited each soil material may be in the wilderness. Soil horizons usually are added back when the site is being stabilized.

Regenerating Subsoil Horizons

If part of the B horizon is missing, it is added back first. If possible, the goal is to match the original soil profile, restoring its hydrologic characteristics. Rock or gravel may be a component of the B horizon. If you add rock and gravel, mix them with soil to fill large voids and air pockets.

Otherwise, fine materials may settle deep into the rock fill, leaving surface roots exposed in the empty spaces between the rocks.

In the wilderness, subsoil may be removed carefully from slumps on trail cutbanks, from tree wells, or from other areas where the mineral soil is exposed naturally. When borrowing soil, try to do so in a manner that will be unnoticeable and will have the least impact on the environment. In some soils, coarse fragments of wood or weathered rock have significant water-holding capacity or nutrient content and they should be included (Whitney and Zabowski 2004).

Regenerating Topsoil Horizons

Topsoil is added on top of the subsoil. Topsoil is best collected in the project location, if you can do so without causing unacceptable damage. Ideally, the topsoil should be from the same plant community you are seeking to replace through restoration. That soil will have similar properties to the soil that was lost from the disturbed site, and it will have the micro-organisms needed for successful restoration as well as the seeds of native plants. If available, clumps of topsoil may retain pore structure better than sieved or mixed topsoil.

Do not place finer textured materials, such as loams, over coarser textured soils, such as sands or gravels. The finer soils will retain more water than the coarse subsoils and will not allow the water to drain deep into the profile. Roots will tend to remain shallow and the plants will be prevented from developing deeper, drought-resistant root systems. If you cannot avoid placing fine soils over coarse soils, mix portions of each horizon to eliminate a clear textural boundary between the horizons.

Often, the best sources of topsoil (and vegetation for transplanting) include soil that is salvaged during a companion project, such as trail construction or even road construction. Organisms can survive for several months in stockpiled topsoil. If the topsoil must be stored for longer than several months, a cover crop should be planted on the windrows of topsoil to maintain biological processes. Even if salvaged topsoil completely dries out during storage, it is a valuable resource for restoration.

Other sources of topsoil might include soil that collects in drain dips along trails, soil salvaged when new drain dips are constructed, soil salvaged when removing the trail berm (also a good source of transplants), tailings scavenged from rodent burrows (such as marmot burrows), or soil collected from the roots of windthrown trees. Sometimes eroded topsoil can be borrowed from depressions where it has settled, without leaving obvious scars (figure 3–28a).

Figure 3–28a—Collecting topsoil without harming wilderness lands is a challenge in restoration projects. Possible sources include topsoil skimmed from temporary ponds or topsoil salvaged when drain dips are maintained along trails nearby.

Regenerating Organic Horizons

Depending on the site's characteristics, duff and plant litter may be added as the final surface layer. The duff will provide a source of nutrients as it continues to break down. The duff and litter also help prevent erosion and compaction by deflecting raindrops.

Duff may be mixed accidentally with the soil during planting. You can avoid this possibility by adding duff as a final mulch after planting is complete. Match the duff to the plant community you are working with. For example, if the restoration site is under trees, duff could be removed carefully from nearby tree clumps. Decomposing grasses, sedges, and forbs would be a more appropriate duff material in meadows. Duff often accumulates in pockets, such as in depressions on talus slopes, under shrubs, or in areas sheltered from the wind.

3.2.3c Amending Altered or Depleted Soils

If soil testing shows that the pH or nutritional content of a soil has been altered, the soil may require treatment or amendment, not just additional material. Naturally occurring organic material may have been stripped away, requiring replacement. A number of treatments are available. The best possible option, especially for wilderness or backcountry sites, is topsoiling. Topsoiling is adding a layer of surrogate topsoil from another source. Often the layer needs to be no more than a few inches thick to provide the nutrients, micro-organisms, and soil functions required by locally adapted native plants. The organic material may be duff collected from areas nearby, minimizing the difficulty of hauling the material.

Other methods for ameliorating soil conditions include the addition of soil amendments or fertilizer. The term, "fertilizer," refers to elemental nutrients, usually in a mix, that are applied to support seedling emergence after germination and to promote root penetration, shoot growth and vigor, and flower and seed production. Nutrients also can be added by using soil nutritional supplements. Typically these are plant, animal, or mineral materials that may contribute to the long-term improvement of soil structure. Balancing these nutrient inputs for the correct plant response is difficult and differs with each nutrient (see section 3.2.3d, *Evaluating Soil Nutrients and Chemical Conditions*).

Additional sources of organic material include commercial compost, peat moss, or Cocobrick. Each source has advantages and disadvantages.

Compost (figure 3–28b) has long been a superior choice for home gardening and growing crops. Compost provides a good source of organic materials and nutrients that allows for a slow release of nitrogen. Compost also has many potentially beneficial soil micro-organisms.

Figure 3–28b—Compost from an urban composting facility provided organic material and nutrients for a restoration research project in the Eagle Cap Wilderness, OR.

Compost was used successfully in the Eagle Cap Wilderness in Oregon as part of a restoration research project (Cole and Spildie 2000). Treatments including scarification, planting, and soil amendments were examined separately and in combinations. A portion of the study compared plots treated with organic material to plots treated with organic material plus additional compost. A 1-inch- (25-millimeter-) layer of organic material (moistened peat moss mixed with well-decomposed organic matter that had been collected locally) was applied to both plots and mixed to a depth of 3 inches (75 millimeters). Compost was spread 1 inch (25 millimeters) thick, watered, and worked into the top 4 inches (100 millimeters) of the soil. The combination of organic material plus compost outperformed the other treatments, supporting higher seedling densities, taller seedlings, and more canopy cover.

During a similar study in Montana, Zabinski and Cole (2000) found that adding compost benefited just one species, pearly everlasting (*Anaphalis margaritacea*). This study found that lack of soil moisture was more of a limiting factor than soil nutrients and organic matter, despite soil tests showing changes in soil chemistry on the disturbed site. That was also the case in Juelson's study at the Enchantment Lakes Basin in Washington (2001).

The use of imported compost in wilderness introduces a dilemma—should nonnative micro-organisms be introduced to the wilderness environment, even if they are potentially beneficial? In addition, compost may introduce disease organisms and nonnative plant seeds.

If compost is used, it should be stored for 1 or 2 years in an aerobic environment such as windrows so it is thoroughly composted; if the compost is too hot (has too much nitrogen), it will withdraw nitrogen from the plants. Compost also should be certified and tested to be weed free, although weeds can still be picked up in storage or transit. Using a liquid compost product or making your own compost tea will help alleviate weed concerns, but such treatments do not add organic material to the soil.

Using organic matter collected on the site fulfills many of the same functions as compost. It provides local microbial inoculum and it may provide a source for sustained release of nitrogen. An earthy smell produced by the filamentous bacteria Actinomycetes suggests that other microbes are active as well. Inactive soils will have little or no dirt smell. Wetland soils may have the sulfurous smell of rotten eggs.

Peat moss is used primarily to improve moisture retention in wetter environments, although in drier environments it could reduce water availability compared to clay soils. Peat bogs are not a renewable resource on a human time scale and such ecosystems are at risk of being depleted. Coconut fiber products provide a more sustainable alternative and are easy to transport in their compressed form. A Cocobrick is about the size of a loaf of bread, and can be placed in a bucket of water overnight to rehydrate.

Use of Fertilizers

Fertilizers or soil amendments may be needed when the soil does not have the nutrients to establish the desired vegetation. If soils are compacted, fertilizer may make up for the reduced function of soil micro-organisms and the decreased volume of soil where roots can grow. The addition of fertilizer also will produce the maximum growth during short growing seasons (Hingston 1982).

Native plants are adapted naturally to the nutrient content of their native soils. Unless the topsoil layer is missing from a restoration site, the use of soil amendments or fertilizer is generally not necessary and could well be counterproductive. Soil nutrients are just one of many limiting factors. Often, another factor, such as soil moisture, will be the key factor limiting plant reestablishment (Chapin 1992).

Topsoiling, mulching with organic matter that will rebuild the soil, establishing nitrogen-fixing native plants, and inoculating plants all are better options than applying fertilizer. If these techniques are not an option, fertilizer will help to establish vegetative cover initially. Fertilizer generally favors nitrogen-hungry grasses, sometimes at the expense of mid- to late-seral species, reversing the pattern of natural succession (Belnap and Sharpe 1995). This is especially true if the fertilizer is one of the common, quick-release chemical formulations that are highly soluble in water.

If topsoil is completely missing, several years of ongoing maintenance fertilization may be required. The plants will continue to need fertilizer until an organic soil layer is reestablished through decomposition of dead plant and animal matter.

The potential disadvantages of fertilization include:

- Burning the roots of emerging plants with too much nitrogen
- Increasing the damage by grazing animals that are attracted to the most palatable plants
- Retarding reestablishment of soil mycorrhizal fungi
- Stimulating weeds at the expense of native plants

- Creating a nutrient pulse that is rapidly leached away
- Disrupting the function of soil micro-organisms
- Artificially supporting plants without rebuilding soil structure

Arid lands are particularly prone to weed infestations. Restorationists should maintain low soil nutrient levels that approximate the natural condition. In a bunchgrass community, Belnap and Sharpe (1995) applied sugar at the rate of 200 pounds per acre (224 kilograms per hectare) to stimulate soil micro-organisms that would tie up soil nitrogen, discouraging the establishment of grasses and weeds while benefiting shrubs.

Overfertilization can cause adjacent water bodies to become eutrophic (rich in nutrients, but possibly poor in oxygen). Surface runoff also can carry fertilizer downslope, where it may be undesirable. Over time, chemical fertilizers leave a buildup of byproducts, including salts and heavy metals that may be toxic. Such problems are unlikely at wildland sites, given the low rates of application.

Fertilization is used extensively during reclamation of strip mines, where topsoil is missing from large acreages. In other cases, fertilization is used to increase forage for grazing.

Large-scale restorations tend to use synthetic fertilizers or sewage sludge to provide missing nutrients. In addition, they sometimes incorporate vegetative matter into the soil. Chemical fertilizers tend to weigh less than organic fertilizers, reducing the problem of transporting them. If chemical fertilizers are used, a slow-release formulation is preferred, especially for projects in arid lands where excess nitrogen will stimulate weeds. Fertilizers with chelated nutrients don't leach through the soil as quickly as other fertilizers.

Organic fertilizers may be made from plant materials, animal materials, or crushed minerals. Organic fertilizers tend to release nutrients at a slow rate, but some may do so too slowly for plants. The nutrients last longer in the soil, are taken up as the plants need nutrients, and with the exception of manure or urea, are less likely to pollute nearby water sources. Soil labs generally report suggestions for using chemical fertilizers. If you are interested in using organic fertilizers, select a suitable soil lab that will work with you, such as a lab that works with organic growers.

The respective amounts of the macronutrients in fertilizers are expressed as percentages of nitrogen (N), phosphorus pentoxide (P_2O_5), and potassium oxide (K_2O). For example, a 20–10–5 formulation is 20-percent nitrogen, 10-percent phosphorus pentoxide, and 5-percent potassium oxide. Often, the fertilizer formulation is expressed simply as N–P–K. For instance, someone may say "The N–P–K content is 16–48–0." The percentage of elemental phosphorus in phosphorus pentoxide is calculated as the percentage of phosphorus pentoxide multiplied by 0.43. The percentage of elemental potassium is calculated as the percentage of potassium oxide multiplied by 0.83 (Redente 1993).

Chemical or organic fertilizers can be used as an interim solution to make up for the lack of nutrients. An agricultural supply company can help calculate an amendment prescription if the soil scientist on your team is not accustomed to working with soil amendments. Agricultural resources are listed in chapter 5, *Tools of the Trade and Other Resources.* You may also ask your local county extension agent or one of the increasing number of restoration-oriented consulting companies for suggestions.

3.2.3d Evaluating Soil Nutrients and Chemical Conditions

Soil tests use various laboratory extracts to estimate the amount of a particular nutrient that would be available to plants for some estimated period of growth. There are many different soil tests with many different interpretations—don't take test results literally. Also, wildland plants tend to have lower nutrient requirements and to need the nutrients longer than agricultural plants. Unfortunately, most soil tests were developed for agricultural systems. Always ask yourself what type of test is being used for a given nutrient and what an appropriate value would be for the field site. Some indicators of appropriate values can come from the vegetated reference site or from low-input managed systems like unimproved pastures or forests.

Soil nutrient evaluation has two steps: correlation and calibration. Correlation is the process of relating the results from the soil nutrient tests to the plant's response. Tests from an area on the reference site that has adequate plant growth can help indicate when nutrient levels are sufficient. Calibration is the process of specifying the amount of amendment needed for plant growth goals. Calibration requires knowing how much amendment is needed, if any, to bring the soil test results to an acceptable level.

Work with a soil scientist to learn how much amendment is needed, or establish several small field trials with low, medium, and high amounts of amendment. The plants' responses will tell you the correct amount of amendment. As you read through the following sections on various nutrients or soil conditions, keep the two steps in mind:

- What is the relationship between adequate plant growth and soil test results (correlation)?
- What amount of amendment would correct the problem and how long would it be needed (calibration)?

Soil Reaction (pH)

Soil pH is a measurement of acidity or alkalinity. A pH of 7.0 is neutral. Acidity increases exponentially below pH 7.0, while alkalinity increases exponentially above pH 7.0. Most soils have a pH between 5.0 and 7.5. Natural soils may lack certain nutrients or have tendencies to be alkaline or acidic. Often the native flora is adapted to these conditions and no correction is necessary. For example, a peat bog might have a pH of about 4.0, while an alkaline flat might have a pH of about 8.5. Soil tests also will address any toxicity issues and measure the soil's cation exchange capacity (CEC), which affects how readily plants take up nutrients.

The pH level tells how acid or alkaline a soil is, but it does not tell how much amendment is needed. For example, the pH of a cranberry may be equal to that of a grapefruit, but it will take much more antacid to neutralize all the acid in a grapefruit than in a cranberry. Consider having a soil scientist conduct buffering and neutralization tests to help estimate the amount of amendment that is needed or you can conduct field trials using several levels of lime (for excessively acid situations) or sulfur (for excessively alkaline situations) amendments. These amendments may take several months, or a wet season, to work. At an abandoned mine, acid mine drainage may neutralize even large amendments of lime and the soil eventually will become more acidic. On the other hand, the small amount of acidity in litter added as a duff layer usually will be neutralized by the soil or by decomposition.

Nitrogen (N)

Nitrogen is an essential nutrient element that forms a major component of plant proteins. Proteins form enzymes that help the plant grow, produce chemicals that make the plant unpalatable, produce viable seed, and perform other vital functions. Nitrogen availability increases root growth, enhancing the absorption of phosphorus, potassium, and other nutrients (Hingston 1982).

Nitrogen in Plants

Plants that have too little nitrogen grow poorly and may be too weak to survive drought or grazing. Their leaves may turn yellow or purple and drop early.

On substrates that are very deficient in nutrients, small nitrogen amendments may improve plant health and size and increase nitrogen fixation. On the other hand, if too much nitrogen is added to soils, weeds may find it easier to invade plant communities. Large amounts of additional nitrogen may decrease the ability of nitrogen-fixing plants to form the nodules where fixation takes place.

Often, nitrogen is added at seeding, but excess nitrogen (particularly from quick-release chemical fertilizers) can burn the roots of seedlings as they germinate. Too much nitrogen can reduce root growth and can prolong the vegetative growth phase, delaying the start of flowering and seeding. In addition, too much nitrogen may increase the succulent growth that attracts grazing animals.

At many sites, no additional nitrogen is needed. If nitrogen appears to be deficient, try to keep amendments at the low end of the scale. Because plants take several seasons to complete root growth, the most beneficial scheme for regenerating wildlands plants on low-nutrient, drastically disturbed sites is to provide low levels of available nitrogen for several years until the plant community is fully reestablished.

Nitrogen in the Soil

Nitrogen is found in soils either in inorganic or organic forms. The inorganic (mineral) forms can be highly soluble and mobile. In the form of ammonia (NH_3), nitrogen volatilizes readily from alkaline soils back into the atmosphere. In the form of nitrate (NO^{3-}), nitrogen leaches readily into the ground water. In neutral to acid soils, nitrogen often is in the ammonium form (NH^{4+}) that is held by the negative charge on the surface of mineral and organic matter. Bacteria get energy by oxidizing ammonium to nitrate, so the ammonium form may not last long in the soil.

When soil is waterlogged, bacteria can convert nitrate to N_2 gas (the original atmospheric form), in which case the fertilizer or mineralized nitrogen is lost from the "plant available" pool. Regenerating soil nitrogen pools on disturbed sites involves preventing nitrogen from being lost and re-creating some approximation of the nitrogen cycles that existed on the site before disturbance.

Typically, wildland systems have very large pools of humified soil organic matter, of which only 1 to 2 percent are decomposed (mineralized) each year. The amount of nitrogen in inorganic (mineral) forms at any one time is small.

For example, the oak/annual grass savanna of northern California has 2,605 pounds of total nitrogen per acre (2,920 kilograms of total nitrogen per hectare), of which 51 pounds per acre (57 kilograms per hectare) is mineralized each year through decomposition (Jackson and others 1988). Only 2.05 pounds of nitrogen per acre (2.3 kilograms of nitrogen per hectare) is in the inorganic forms (ammonium and nitrate) that are extracted by standard soil analysis tests.

In the Lake Tahoe Basin white fir forest, an average of 1,095 pounds of total nitrogen per acre (1,228 kilograms of total nitrogen per hectare) accumulated in the soil organic matter, with 23 pounds of nitrogen per acre (26 kilograms of nitrogen per hectare) being released by mineralization each year (Claassen and Hogan 2002). Less than 4.5 pounds of nitrogen per acre (5 kilograms of nitrogen per hectare) were extracted by standard soil analysis tests.

Many other examples of organic matter pools in wildland soils are reviewed in Claassen and Hogan (1998). The pool of total nitrogen is in the low thousands of pounds of nitrogen per acre (or kilograms of nitrogen per hectare), while the mineralizable form that is available for plant growth is about 1 to 2 percent of the total nitrogen—tens of pounds of nitrogen per acre (or kilograms of nitrogen per hectare). The small, variable amount of inorganic nitrogen (ammonium or nitrate) has little bearing on predicting plant growth, except on undisturbed sites.

Sources of Nitrogen for Soil Amendments

The most foolproof way to regenerate soil nitrogen pools is to bring in topsoil that similar in quality and quantity to the topsoil that had been on the site originally. Using topsoil provides a sustainable long-term source of nitrogen complete with soil micro-organisms (Redente 1993), seeds, and possibly plant rhizomes. The nitrogen pools in topsoil are large enough to allow plant growth to regenerate after repeated disturbances such as grazing, fire, or plant disease.

However, if just 1 percent of the total nitrogen is being mineralized each year, several thousand pounds of nitrogen will be needed per acre (or kilograms of total nitrogen per hectare), requiring applications of about 8 to 12 inches (200 to 300 millimeters) of topsoil, depending on the amount of organic matter in the topsoil. It may be cost prohibitive or logistically infeasible to provide this much topsoil.

An alternative, less intensive approach would be to provide the nitrogen needed for the plant community to regrow. The plant community will need several years to fully establish, meaning that nutrients need to be available for 2 or 3 years after amendment. Most chemical fertilizers are very soluble, ensuring that the crop or lawn gets quick access to the complete dose of nutrients. If standard chemical fertilizers were used for wildland restoration, much of the fertility intended for the second and third year of plant growth would leach away or be used to grow weeds.

Chemical coatings can slow the release of nitrogen. Fertilizer prills with polyurethane coatings are more likely to survive application by hydroseeding than sulfur- or resin-coated prills. Once weaker coatings break apart, the fertilizer is released just as fast as it would have been without the coating.

Synthetic nitrogen fertilizers come in the form of urea and ammonium nitrate, both derived from petroleum products. Urea is less expensive. Its disadvantage is that it is converted to nitrogen gas rapidly, leaches quickly, and is toxic to some plants. To compensate for the amount lost as gas, twice as much urea must be applied as would be indicated otherwise, and it should be applied on a cool, humid day. Ammonium nitrate is taken up more readily by plants, and is more effective in cold or very wet soils (Hingston 1982; Potash and Aubry 1997).

Higher availability may be more important in cold or very wet soils (Hingston 1982; Potash and Aubry 1997). Even the "slow release" chemical fertilizer formulations release nitrogen more quickly than does organic matter in topsoil.

The ratio of decomposable carbon to decomposable nitrogen determines the rate of nitrogen release from organic materials. As microbes decompose carbon in organic matter, their populations grow and they need to incorporate nitrogen to build their biomass. If the ratio of carbon to nitrogen is about 20, microbial populations grow smoothly. But when the carbon-to-nitrogen ratio is higher than 25, microbes take up the majority of the available nitrogen, a process called immobilization. Because plants are less efficient at taking up nitrogen than microbes, plants will be left with access to too little nitrogen.

The Carbon-to-Nitrogen (C:N) Ratios of Selected Materials

(Haydon 1991; Martin and Gershuny 1992)

Materials	C:N Ratio
Alfalfa hay	13:1
Seaweed	19:1
Rotten manure	20:1
Apple pomace*	21:1
Leaves	40–80:1
Oat straw	24:1
Wheat straw	80:1
Paper	170:1
Decayed hemlock	200:1
Sawdust	400:1
Fresh hemlock	500:1

*Pulp after juice has been squeezed

Eventually, microbes use up the carbon source. As the microbes decline, more nitrogen becomes available. In contrast, organic amendments with a low carbon-to-nitrogen ratio can support microbial growth and release some of the extra nitrogen, a process called mineralization.

Woody materials may have a carbon-to-nitrogen ratio of 100 or more, so they tend to immobilize nitrogen in the surrounding area. A dead insect or rodent, on the other hand, has a carbon-to-nitrogen ratio of 5 to 10, so as the carbon decomposes, abundant nitrogen is available to be released, or mineralized.

Organic soil amendments have a range of release rates (Claassen and Carey 2004) depending on their carbon-to-nitrogen ratios and on their stage of decomposition. Some organic materials release nitrogen as quickly as chemical fertilizers and others barely release nitrogen. Several agricultural byproducts are available that release a third to half of the total nitrogen content initially, then release the rest more slowly. For instance, a product called Biosol is made from the remains of microbes used to produce pharmaceuticals. It probably decomposes in much the same way that dead microbes decompose in the soil.

Sources of nitrogen-rich organic amendments include compost and well-composted manure, but take care to find a quality source. Clopyralid, an ingredient of commercial herbicides such as Transline, Stinger, and Reclaim, can be present in compost and manure for a year—even longer under anaerobic conditions. Be wary of sewage sludge, which can have toxins (including heavy metals), and of cottonseed meal, which can have pesticide residues. Less toxic sources of nitrogen include blood meal, canola meal, and some types of vegetative residue.

Yard waste composts provide a long-term release of nitrogen similar to that of topsoil (Claassen and Carey 2004). The fibrous materials in the composts also improve surface infiltration of rainwater.

Biological nitrogen fixation occurs when free-living soil bacteria and algae fix atmospheric nitrogen. This mechanism can fix up to 50 pounds of nitrogen per acre (56 kilograms per hectare) per year, although a sagebrush community that has very few nitrogen-fixing plants may fix just 2 pounds of nitrogen per acre (2.24 kilograms per hectare) per year. Ceanothus in northern Oregon fixed 9.8 pounds of nitrogen per acre (11 kilograms per hectare) per year (McNabb and others 1979). Red alder fixed 50 to 300 pounds of nitrogen per acre (56 to 336 kilograms of nitrogen per hectare) per year (Miller and others 1989).

Nitrogen fixation requires a lot of energy. Plants that are struggling to survive cannot be expected to fix much nitrogen. They may even deplete nitrogen in the soil as they attempt to become established (Harvey and others 1989). On drastically disturbed sites, a small amendment of nitrogen may have to be added to get the nitrogen fixation system functioning.

Falling rain collects nitrogen compounds from the atmosphere that become available to plants as the rain percolates into the soil. Volcanoes, forest fires, and industrial emissions contribute ammonium to the atmosphere. Nitrate (NO_3) is formed in the atmosphere by electrical discharge during thunderstorms, by ultraviolet light, and in coastal areas by saltwater that evaporates and suspends salts in the air (figure 3–29). For semiarid regions unaffected by air pollution, the nitrogen input from thunderstorms is estimated at 2 pounds per acre (2.24 kilograms per hectare) per year (Redente 1993; Salisbury and Ross 1978).

In many conditions, no nitrogen amendment may be necessary. On small disturbed patches (trails, a single campsite) enough nitrogen may be available in the soil for plant growth. In areas downwind from metropolitan areas, atmospheric deposition may provide enough nitrogen. In disturbed areas that still retain some of the preexisting topsoil, tilling may allow enough nitrogen to be mineralized for the plant community to regenerate. Nevertheless, the more a site has been disturbed, the more likely that soil organic matter levels are low and that long-term supplies of nitrogen are insufficient for plant growth and community development.

The trick for appropriate amendment with fertilizers or soil amendments is to estimate the amount of nitrogen needed for each of the first two or three growing seasons. Not only do plants use nitrogen to produce roots and shoots each year, but some nitrogen will end up in plant litter, residual soil organic matter, woody stems, and the microbial community. Given the wide range of ecosystems, the amount of nitrogen any particular ecosystem requires may vary widely. When a site is restored, nitrogen amendments will be needed for each of the first several years until the various components of the plant community have regenerated.

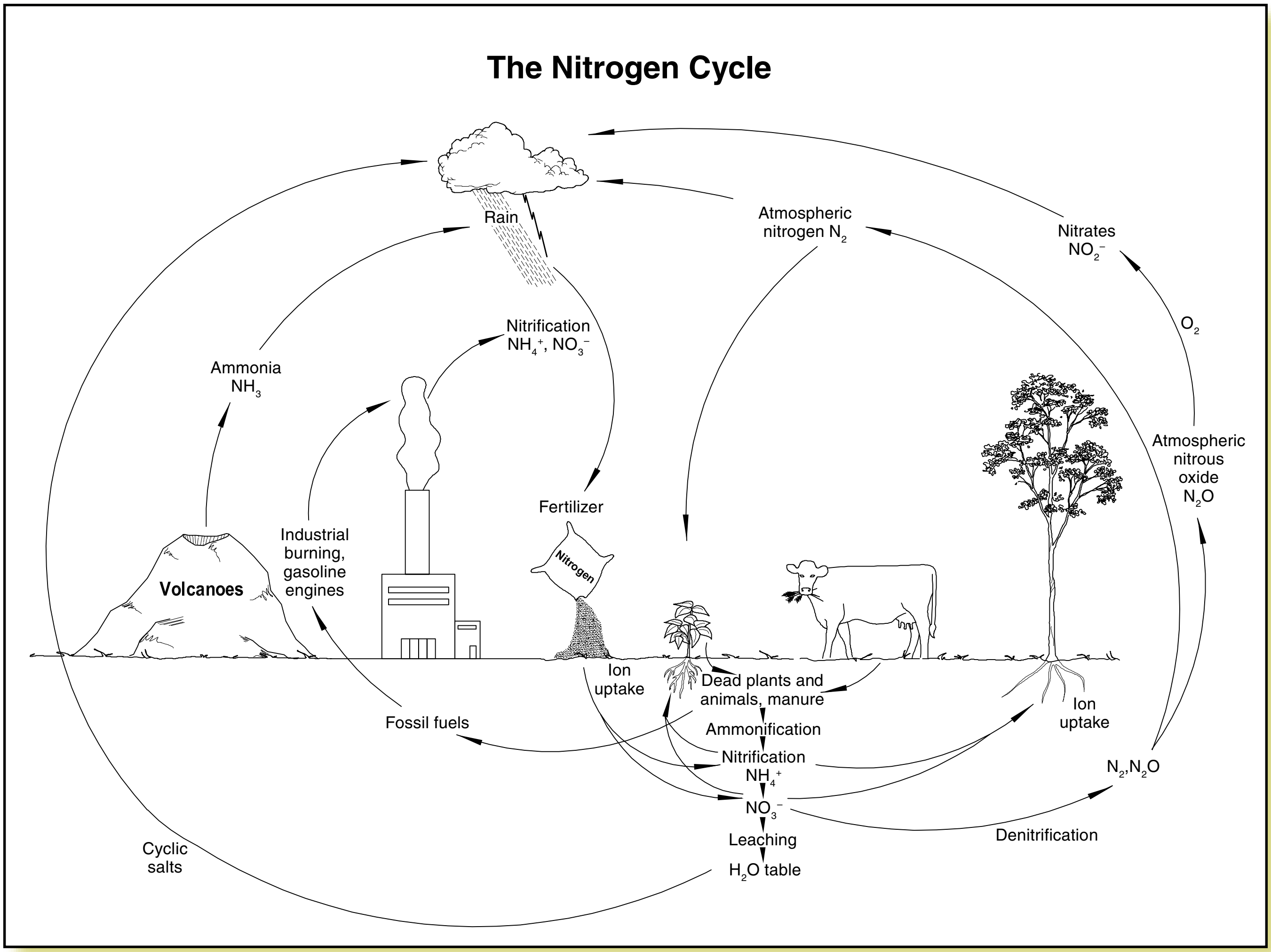


Figure 3–29—The nitrogen cycle.

Testing for Soil Nitrogen

Testing soils for relevant pools of plant-available soil nitrogen is difficult. Commercial soil tests are easily obtained for total nitrogen and for extractable nitrogen. The total nitrogen tests are called total elemental nitrogen analyses or if an acid digest is used, Kjeldhal nitrogen tests. These tests measure the total amount of nitrogen in the sample, including nitrogen that is not available to plants.

The extractable nitrogen tests are called potassium chloride (KCl) extracts or acetate salt extracts. These tests measure only the ammonium or nitrate that is in the soil solution being tested or that is held on the soil surfaces, a very small pool.

For an existing topsoil, nitrogen mineralization is steady enough that a quick test of extractable nitrogen will show that the process is active (1 to 10 parts per million extractable nitrogen) and that there is enough total nitrogen to keep it going for several decades. Any time the soil is disturbed or large amounts of amendment are added, it is difficult to know how much nitrogen is being produced and how long it will last.

Sites with no vegetative cover can accumulate nitrate from rainwater for a decade or so. Soil tests will detect adequate levels of nitrate and predict that corn can be grown. However, because these sites may have no organic matter (measured by total nitrogen and total carbon), the small pool of extractable nitrogen cannot be replaced once it is taken up by plants, probably within the first month of growth. Plant growth on the site would be short lived.

Until tests are available for intermediate- and long-term nitrogen availability, determining how to evaluate and amend soils depends more on empirical experience or field test plots than on laboratory tests.

Phosphorus (P)

A lack of phosphorus is the second most common soil deficiency, especially on arid lands. Phosphorus is lost through erosion of mineral and organic sediments. In contrast to nitrogen, phosphorus is immobile and insoluble in the soil. Overapplication of phosphorus is not toxic to plants, but may reduce colonization by mycorrhizae. Because of its immobility, phosphorus is not prone to leaching and must be amended into the plant's root zone (an area extending not only under the plant's canopy, but half the canopy's width beyond the canopy).

Phosphorus stimulates root growth, which is very important for seedlings. It also promotes maturity, including seed production. Phosphorus strengthens stems, helps the plants absorb nutrients, and increases disease resistance. Plants that are deficient in phosphorus may be stunted. Seedlings may have purplish foliage (Hingston 1982; Redente 1993).

Phosphorus is present in many compound fertilizers, including ammonium nitrate-phosphate (23–23–0) and ammonium phosphate (11–48–0). If only phosphorus is needed, triple superphosphate fertilizer (0–46–0) is the common choice. This formulation also contains sulfur and calcium (Hingston 1982; Redente 1993).

Organic amendments containing phosphorus include rock phosphate, basic slag, bonemeal, bloodmeal, cottonseed meal, and activated sludge. All these are applied at three to four times the rate of triple superphosphate (Rodale 1961). Because these amendments also may have significant amounts of nitrogen, be sure to balance these two elements in your amendment design. Steamed bonemeal and pelletized rock phosphate (with a lignosulphate binder) are reputed to be the best source of organic phosphorus (IFM 1995). Tilling in legumes as a green manure also will add phosphorus (Rodale 1961).

In clayey soils, the soluble phosphorus in fertilizer will eventually bind with clay particles, making it unavailable to plants temporarily. Cold soils tend to inhibit the absorption of phosphorus.

Legumes have a high phosphorus demand. Ample supplies of phosphorus will stimulate nitrogen fixation in legumes.

Soil tests are used to judge when to amend phosphorus. The extracts are generally different for acid soils than for neutral or alkaline soils, and have different minimum thresholds indicating when an amendment might be needed. Generally, extract levels less than 10 parts per million (or about 15 parts per million for acid extracts) may be low enough that a phosphorus amendment could help plants grow. Soil conditions may change the amount of phosphorus that might need to be added. Reddish soils (that are coated with oxides), clayey soils (that have a lot of surface area), or volcanic soils (that have reactive minerals) generally bind phosphorus, so they require more phosphorus when they are amended.

Composted organic matter or duff will have phosphorus in organic forms that will not fix onto surface soils as rapidly. Amendment of 110 to 220 pounds of phosphorus per acre (50 to 100 kilograms of phosphorus per hectare) in southern pine plantations has increased plant growth. In the Northwest, however, soils have higher amounts of ambient phosphorus, and their potential for fixing added phosphorus (so it can't leach through the soil) is huge. For this reason, plant response to phosphorus amendment in the Northwest is erratic and the effect of the amendment is unlikely to last for long (Powers 1989).

Potassium (K)

Potassium (K), also called potash, is taken up in large quantities by plants. It helps plants pull water from the soil, is used in many enzymes, improves seed viability, and strengthens the stem. Potassium promotes photosynthesis, root development, plant vigor, and growth, and maturation of flowers, fruits, and seeds. Potassium also increases winter hardiness in legumes (Hingston 1982; Redente 1993). Signs of potassium deficiencies in plants can include dull, bluish-green leaves with yellowing between veins, which progresses to browning leaf tips and spots or patches of discoloration. Older leaves may have rolled edges that appear to have been scorched.

Because potassium is common in minerals, it is less likely to be deficient in the soil than nitrogen or phosphorus. Its availability can be limited in coarse soils. Potassium is more mobile than phosphorus. Leaching generally is not a concern unless soils are sandy or prone to flooding. Potassium is most effective if it is incorporated into the root zone.

Potassium is taken up by waterflow into the plant's roots along with other cations (calcium, magnesium, sodium). The ratio of potassium to other cations should not be too low (less than 1 percent of the soil's cation exchange capacity), or too little potassium will be taken up. So, the extracted amount of potassium (usually around 100 parts per million or more in the soil extract) is less important than the minimum ratio of the different cations on the soil surface. In soils that are alkaline, calcium interferes with potassium absorption.

Synthetic potassium fertilizer is commonly available as potassium chloride, also called muriate of potash (0–0–60). Potassium also is available in compound fertilizers (those that include a range of nutrients).

Organic amendments used to increase potassium in the soil include kelp, manure, plant composts, granite dust, greensand, basalt rock, wood ash, and hay. Kelp is especially high in potassium and also is rich in trace elements. Leaves, canola meal, and bonemeal have less potassium (IFM 1995; Rodale 1961). Potassium is abundant but balanced in plant-based organic matter amendments such as litter and compost, so applying too much amendment is not a problem as it might be in the case of other nutrients.

Calcium (Ca)

Calcium is a component of most rock minerals, plant biomass, and lime. It may be lacking in soils that have become acidified, such as mining spoils. Calcium can be used to increase the pH of the soil, and it stimulates micro-organisms.

Calcium helps plants form cell walls and helps shoots to grow. Calcium (in the form of bonemeal) has long been used as a supplement for plants that grow from bulbs. Calcium increases the availability of phosphorus and decreases the uptake of iron, aluminum, and manganese, which can be present in toxic levels in acid soils.

The symptoms of calcium deficiencies include terminal buds that may fail to develop and leaves that may be distorted by appearing to be rolled forward along the margins or rolled backward toward the underside of the leaves. The edges of the leaves may show yellow bands or they may appear to have been scorched.

Some acid-loving species, such as blueberries and cranberries, cannot tolerate calcium.

Often calcium is amended to increase the soil's pH. Ground calcium carbonate, also called limestone flour, is a good choice if magnesium does not need to be supplemented. Calcium carbonate is one of the safer forms of calcium and is released into the soil more slowly than some other lime amendments. Ground dolomite lime (a blend of magnesium and calcium carbonates) should be used only if magnesium needs to be supplemented. If altering the soil pH is undesirable, gypsum makes an excellent calcium amendment. It contains 23 percent available calcium and 18 percent sulfur. Gypsum is a common amendment on clayey soils where it loosens the cohesion of the clay particles, making the soil more workable (IFM 1995).

Magnesium (Mg)

Magnesium occurs naturally in limestone formations. Magnesium plays a role in the formation of chlorophyll, aids in the assimilation of phosphorus, and regulates respiration. Plants with magnesium deficiencies may be discolored between the veins of older leaves or may have yellow leaves with brilliant tints (before the leaves drop). Grasses with magnesium deficiencies may be dwarfed and may have leaves with yellow stripes between the veins.

If the soil's pH does not need to be changed, magnesium sulfate is the best supplement to correct a magnesium deficiency. In acid soils, ground dolomite lime is good.

Sulfur (S)

Sulfur is fixed into the soil from the atmosphere. However, soils may still be lacking in sulfur. Soil tests for sulfur are not very accurate, so the results are approximate. The levels of sulfur on the reference site may be the best indicator of the levels needed by plants at the restoration site.

Sulfur stimulates root growth, chlorophyll production, seed production, and the formation of root nodules on legumes, which need more sulfur than grasses. Plants convert sulfur into proteins and amino acids.

Sulfur deficiencies observed in plants include leaves that turn light green, then yellow; plants that are small and spindly; and seed that matures late. In legumes, nodule formation is reduced.

Synthetic sulfur is found in compound fertilizers and is available as elemental sulfur, a byproduct of the petroleum industry. Highly basic soils are treated with the addition of elemental sulfur and certain bacteria (probably already present at the site), which form sulfuric acid, a process that may take many months.

If the soil needs to be acidified, pelletized sulfur may be used as an amendment. Otherwise, gypsum or K-mag can be used. K-mag contains 27-percent sulfur, 22-percent potassium, and 11-percent magnesium (IFM 1995).

3.2.4 Application of Fertilizers or Soil Amendments

With most restoration projects, fertilizer is added during seeding—generally in the fall. However, this timing is for convenience and cost savings. If the fertilizers are very soluble, they will burn the germinating plant roots. A better approach is to fertilize the seedlings once true leaves have appeared on them, but this requires tilling in the fertilizer and may require a separate trip to the site. With this approach, nitrogen is sure to be available when it is needed. Otherwise, it may have leached away before the seedlings need it.

Fertilizer can be broadcast with a spreader—a hand operated "belly grinder." Fertilizer should not be placed directly into planting holes unless the fertilizer is a slow-release formulation. Several formulations of "tea bag" fertilizers are easily dropped into planting holes.

Treating Saline Sites

In theory, if a soil is naturally saline, the native plants already are adapted to saline conditions. But salts can build up in the soil unnaturally because of irrigation with saline water, excessive use of fertilizers, or even because hunters or herders have placed salt blocks. If you notice a salty white crust on the soil, your site may be saline. These conditions typically occur in arid regions and in low-lying areas such as basins and playas.

Two issues arise with saline soils. The initial challenge is to discourage stock or wildlife from pawing and eating salty soil, which is not helpful when you're trying to reestablish native vegetation. In addition, if the salinity level is very high, the soil may be toxic to native plants. The best way to determine whether salinity levels may be too high is to work with a soil scientist.

Salinity can be reduced by flushing soils with copious quantities of water, or by treating soils with gypsum before flushing them. Wildlife or stock disturbance on saline soils can be reduced by reducing salinity or by using a fence or lots of logs to block access to the salty area. If human activities have hindered soil drainage, improved drainage also should be considered.

Some salt crusts are relatively mild, such as those indicated by frost-like white crusts left on pine needle litter in Yosemite National Park, CA, after rainwater pools evaporate. If the site is at high elevations or is not in an area with sedimentary rocks, salts are unlikely to be a problem.

Interpreting Soil Test Results

The soil test results in table 3–4 show comparisons of soil test results at restoration site and a revegetated reference site.

Soil nutrient levels should be evaluated with respect to wildland conditions. Because data on adequate nutrient levels at wildland sites are scarce, a comparison to an undisturbed reference site is valuable. Many of the soil tests are standard agricultural tests, so a large data set is available from agricultural and forestry experiments. If plants survive on your reference site, nutrient levels from that site are more meaningful than levels from agricultural fields.

The pH of the soil in the Enchantment Lakes Basin is less acidic (pH 5.5) at the disturbed site than at the undisturbed site (pH 4.6). Both soils are acidic, but plants adapted to acidic soils can live there. The subsoil at both the disturbed and undisturbed sites was less acidic (pH of 5.8 at the

Table 3–4—An example of results from a comparative soil analysis test of the A_2 soil horizon in the Enchantment Lakes Basin of the Alpine Lakes Wilderness, WA (Juelson 2001). *CEC* stands for cation exchange capacity; *ppm* stands for parts per million; *meq* stands for milligram equivalents.

Test	Disturbed site	Undisturbed site
Potassium	52.5 ppm	94.0 ppm
Potassium saturation of CEC	1.3%	2.0%
Calcium	151 ppm	256 ppm
Calcium saturation of CEC	3.8%	5.4%
Magnesium	7.0 ppm	24.3 ppm
Calcium/Magnesium ratio	13:1	6:1
Sodium	26.7 ppm	17.0 ppm
Sum of exchangeable bases	1.06 meq per 3.5 oz (100 gm)	1.79 meq per 3.5 oz (100 gm)
CEC	10.0 meq per 3.5 oz (100 gm)	11.9 meq per 3.5 oz (100 gm)
pH	5.5	4.6
Lime required for neutralization	6.0 tons per acre (2.7 metric tons per hectare)	15 tons per acre (6.7 metric tons per hectare)
Soluble salts	(1.7 millimhos per millimeter)	(1.4 millimhos per millimeter)
Phosphorus	10.7 ppm	18.7 ppm
Boron	< 0.05 ppm	0.27 ppm
Organic matter	4.8%	9.8%
Estimated nitrogen release (agricultural fields)	140 lb (63.5 kg)	290 lb (131.5 kg)
Nitrate	< 0.4 ppm per 2 lb (0.91 kg)	< 0.4 ppm per 2 lb (0.91 kg)

disturbed site and 5.5 at the undisturbed site) than the soil. Because soil is more acidic on the well-vegetated undisturbed site, acidic conditions at the disturbed site probably are not the cause of poor plant growth.

The CEC (cation exchange capacity) indicates how well the soil can retain nutrient cations. It is moderate at both sites, but is 20 percent lower at the disturbed site. The proportion of nutrient (base) cations is a very low proportion of the CEC. Typically, the proportion of base cations would be more than 50 percent of the CEC. The undisturbed site also has a low proportion of base cations, but it is nearly twice that of the disturbed site. The general numerical picture is of a nutrient-stressed site. The salinity of the soil is very low, as would be expected at a high-elevation site where abundant precipitation leaches salt from the soil.

Specific nutrient analyses include potassium, calcium, magnesium, and phosphorus. Potassium occupies 1.3 (disturbed site) and 2.0 percent (undisturbed site) of the CEC (calculations not shown), which approaches values for poor agricultural soil. Calcium is very low at 3.8 and 5.4 percent of the CEC. Values over 50 percent would be expected, but the vegetated reference site is also low. One could speculate that the overlying organic layer (present on the undisturbed site but missing from the disturbed site) is a significant source of calcium for plant growth. Magnesium also was low, but was equally low on the undisturbed site. Phosphorus levels of 10.7 (disturbed site) and 18.7 parts per million (undisturbed site) are adequate for agricultural plant growth, and would not be viewed as limiting at this site.

The combination of relatively high organic matter levels, 4.8 (disturbed site) and 9.8 percent (undisturbed site), with such low calcium levels is puzzling. Interpretation of soil tests is a complex task and subject to guesswork. One technique to help interpret soil tests is to send in soils that have previously been analyzed, making sure that current results are correct or to send in multiple samples from the site. Such methods increase the cost of sample analysis.

Estimated nitrogen release is a calculated number based on nitrogen release from agricultural-quality organic matter. These values are disregarded for wildland systems except to show differences between sites. The nitrate pools change quickly with weather, plant growth, and season. Any given nitrate value has little long-term significance, except for a well-fed agricultural crop. Appropriate analysis of soil nitrogen levels is difficult for wildland situations. Given the importance of nitrogen in plant nutrition, analysis of wildland soil nitrogen levels is a major research need for revegetation science.

This brief review of soil analyses shows how soil data need to be viewed in relation to each other, in the context of the site, and with a critical eye to whether the tests were appropriate. No distinct thresholds can be defined. Plants can compensate for low levels of nutrient availability by sending their roots deeper or by greater spacing between plants.

3.2.5 Restoring Soil Biota

Depending on the degree of soil disturbance, the plant species being reestablished, and the availability of local topsoil, it may be necessary to inoculate plants with mycorrhizal fungi or nitrogen-fixing bacteria. Some species of plants cannot grow without their associated mycorrhizal fungi. Others may survive, but would not be able to grow, spread, and reproduce. Studies of soil micro-organisms have produced a fascinating, complex, and growing body of scientific information. For the purposes of restoration, the principles can be generalized to establish a fairly simple process allowing you to determine what you need for your project.

Before going into the specifics of working with mycorrhizal fungi, some background is needed. First, if vegetative cover is largely missing from a site, it is safe to assume that the soil micro-organisms have been altered or are gone altogether. Some organisms can survive in the soil for up to a few years without plant cover, but the biota will be radically different from that in areas with a full complement of plant cover. This is the case for most of our highly disturbed wilderness campsites and trails.

About 80 to 90 percent of the Earth's vascular plants are thought to depend on mycorrhizal associates. Plants that do not depend on mycorrhizal associates include the genera *Saxifraga* (saxifrage), *Juncus* (rushes), *Carex* (sedges), and plants in the Brassicaceae (mustard) and Caryophyllaceae (pink) families. These plants are often the first colonizers of naturally disturbed areas, such as the areas left after a glacier recedes (figure 3–30). Often, the early colonizers are replaced as the plant community develops (Cázares 1992). The lack of soil moisture or cold temperatures in arid or alpine regions limits the establishment of mycorrhizal fungi and may limit plant establishment during restoration (Amaranthus and others 1999).

Figure 3–30—As a glacier recedes, the first plants to colonize the raw, exposed soils do not rely on associations with mycorrhizal fungi. Such plants include the graminoids (grasses, sedges, and rushes), members of the mustard and pink families, and plants belonging to the genus Saxifraga.

Most of our weedy, introduced species do not depend on mycorrhizal associations. This characteristic is a key reason why they are able to invade disturbed areas rapidly.

In some cases, the mycorrhizal fungi needed to support young stands of a plant, such as Douglas-fir, differ markedly from those needed by mature stands. Some plants need their mycorrhizal associates all the time, while other species just call on them to help survive drought or resist disease. Sometimes the presence of one type of mycorrhizal fungus can suppress the establishment of another type, affecting survival of the plant species that depend on one species of fungus or the other (Amaranthus and others 1999).

Some species require the establishment of mycorrhizal fungi when they are young. Sometimes whole plant communities (or guilds) that follow each other in ecological succession, such as the shrub communities preceding conifer establishment, have a shared soil microflora. If the conifer species are removed, the shrub community maintains the soil flora, allowing conifers to reestablish (Amaranthus and others 1999).

The following section on the types of mycorrhizal fungi will help you determine which type of mycorrhizal fungi you might need. The most specific way to determine mycorrhizal needs is to read the scientific literature about the selected plant species.

Lacking species-specific information, experiment. To quote Aramanthus and others (1990):

> *The best advice for those working in reclamation [of soil organisms] is to try. One does not have to be a rocket scientist, or even have a high school diploma, in order to experiment. All it takes is common sense—perhaps backed up by a little intuition and access to the proper soil organisms.*

3.2.5a Types of Mycorrhizal Fungi

Worldwide, seven general groups of mycorrhizal fungi are important to distinguish, based on the species of plants you select.

Ectomycorrhizae

This group of mycorrhizae is associated with many tree (figure 3–31) and shrub species. The prefix, *ecto*, refers to the fungal hyphae wrapping a web-like structure around plant roots and colonizing the spaces between the cells without penetrating the interior of the cells. Nutrients are absorbed through the cell walls of the plant's roots. Some plant roots can be linked by ectomycorrhizal hyphae, which can act like a plumbing system that allows nutrients to move from plant to plant.

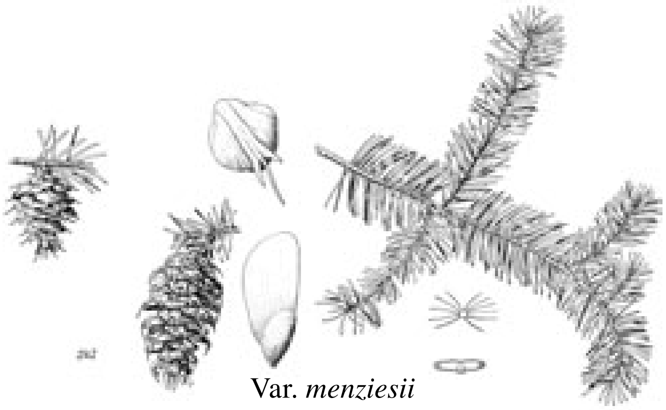


Figure 3–31—Douglas-fir (*Pseudotsuga menziesii*) associates with up to 2,000 different species of mycorrhizal fungi throughout North America (Trappe 1977). Ectomycorrhizal fungi tend to be generalists; one species of fungus can interact with many different species of plants. Drawings courtesy of the University of Washington Press (Hitchcock and Cronquist 1976).

The spores of ectomycorrhizae can travel through the air and through the soil. Because the spores are so mobile, ectomycorrhizal host plants are less likely to require inoculation, even though they will still benefit.

Arbuscular Mycorrhizae

This group is associated with grasses and forbs, and with some shrub and tree species. The prefix, *arbo*, refers to the vesicles of the mycorrhizae, which branch in a treelike pattern. The hyphae of arbuscular mycorrhizae penetrate directly into the cells at the growing tips of plant roots. Vesicular-arbuscular mycorrhizae have large soilborne spores that migrate only short distances through the soil.

In arid and semiarid lands, 90 percent or more of the vascular plant species depend on arbuscular mycorrhizae. The arbuscular mycorrhizae fungi are less diverse than the ectomycorrhizae, but are still generalists. Sagebrush (*Artemesia*), for example, has only four species of fungus that interact with it (figure 3–32), but these fungi interact with other plant species as well (Moldenke and others 1994). Western redcedar (*Thuja plicata*), species of *Ceanothus*, and species of *Rubus* (blackberries and salmonberry) also rely on arbuscular mycorrhizae.

Figure 3–32—At least 90 percent of arid and semiarid land plants rely on vesicular-arbuscular mycorrhizal fungi. Four such fungi species associate with big sage (*Artemesia tridentata*). Drawing courtesy of the University of Washington Press (Hitchcock and Cronquist 1976).

Ericoid Mycorrhizae

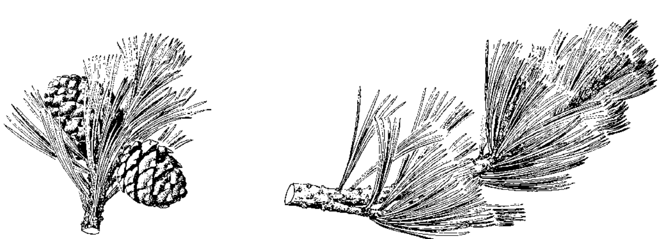
This group is specific to the heath family (Ericaceae), which includes plants such as heather, huckleberry, azalea, rhododendron, Labrador tea, and salal (figure 3–33). If you are working with a plant in the heath family, it will be important to collect inoculum from the same species.

Gaultheria ovatifolia

Figure 3–33—Ericoid mycorrhizae associate with plants of the heath family, such as this slender wintergreen (*Gaultheria ovatifolia*). Drawings courtesy of the University of Washington Press (Hitchcock and Cronquist 1976).

Ectendo Mycorrhizae

This group is found predominately on pines (*Pinus*, figure 3–34), and can occur along with ectomycorrhizae. Some plant species that are not normally thought to be mycorrhizal, such as sedges, have been colonized by ectendo mycorrhizae, particularly in alpine or arctic areas where arbuscular mycorrhizae are not well represented.

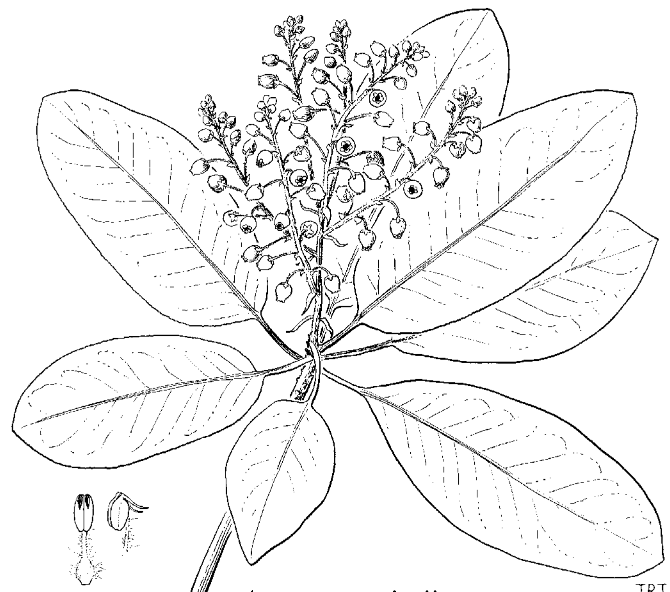


Pinus albicaulis

Figure 3–34—Endomycorrhizae associate with pines, such as this whitebark pine (*Pinus albicaulis*), and are more likely to be represented in subalpine or alpine environments. Drawings courtesy of the University of Washington Press (Hitchcock and Cronquist 1976).

Arbutoid Mycorrhizae

This group is specific mostly to Mediterranean species, but also interacts with *Pyrola* (wintergreen), *Arbutus* (madrone, figure 3–35a) and *Arctostaphylos* (manzanita and kinnikinnick, figure 3–35b).



Arutus menziesii

Figure 3–35a—Arbutoid mycorrhizae associate with a few North American genera, including genera in the heath family such as *Arbutus* (madrone). Drawings courtesy of the University of Washington Press (Hitchcock and Cronquist 1976).

Arctostaphylos uva-ursi

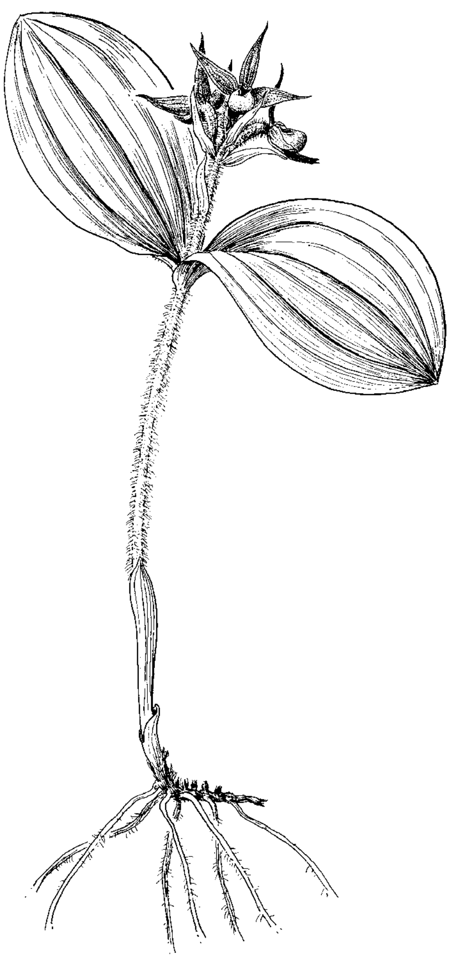
Figure 3–35b—Kinnikinnick (*Arctostaphylos uva-ursi*) is an excellent restoration species because it spreads readily. Drawings courtesy of the University of Washington Press (Hitchcock and Cronquist 1976).

Dark Monotropoid Septate Endophytes

Not much is known about this group of mycorrhizal fungi, but it can be associated with any plant species. The dark-brown hyphae penetrate inside root cells.

Orchidaceous Mycorrhizae

As the name suggests, this type of mycorrhizal fungi is specific to the orchid family (figure 3–36). The hyphae form a spiraling structure that looks like spaghetti in the plant's root cells. While it seems unlikely that a wilderness restorationist would select an orchid species for restoration, the orchidaceous mycorrhizae are mentioned here to point out the specific needs of this beautiful and often rare group of plants.



Cypripedium fasciculatum

Figure 3–36—Orchidaceous mycorrhizae associate with plants of the orchid family, such as this rare clustered ladyslipper (*Cypripedium fasciculatum*). Drawing courtesy of the University of Washington Press (Hitchcock and Cronquist 1976).

3.2.5b Inoculating Plants With Mycorrhizal Fungi

While commercial cultures of some mycorrhizal fungi are available, in wilderness areas it is more appropriate to inoculate plants with mycorrhizal propagules collected near the restoration project area. Mycorrhizal propagules are spores, hyphae, and plant root fragments containing mycorrhizal fungi.

Preserving biological integrity should be a primary project goal. Too little is known about the effects of introducing new soil organisms, such as nonnative mycorrhizal fungi. They might harm the beneficial native organisms. Collecting inoculum locally also is more likely to be effective because the correct fungal species are guaranteed to be present. Some of the commercially grown inocula contain completely different species that are derived from tropical soils and may not be suitable for North American native plant communities (Cázares 2002).

Although there are many ecological uncertainties about the use of commercial inoculum in wilderness or pristine habitats, commercial inoculum could be a last resort in soil reclamation projects where mycorrhizal propagules do not exist.

The technique for collecting mycorrhizal inoculum is quite simple; dig into the root zone of the type of plant species (or group) that you will be using for restoration. Remove some soil, including small pieces of roots (figure 3–37). This soil is your inoculum. If local topsoil or organic matter is being used, the appropriate fungal spores also are likely to be present in the topsoil or organic matter.

You may choose to inoculate soils when growing plants in the greenhouse or on the restoration site when planting them. Inoculating both times will enhance success. Inoculation is most successful when plants are seedlings. Inoculating

Figure 3–37—Mycorrhizal inoculum is collected by removing soil and small root fragments from the root zones of healthy populations of the same species that is being planted. The plug of vegetation dug up for this purpose is replanted into its hole after the inoculum has been collected.

a more mature plant at the restoration site after it has been grown in a nursery is less likely to succeed than if the plant is inoculated when it is being grown at the greenhouse.

If plants are being propagated offsite, use the inoculum as part of the planting medium. It is critical for the growing roots to contact fungal spores. Partially fill the flats or containers with potting soil, add a thin but continuous layer of inoculum, add the seed and cover the seed with potting soil. Mycorrhizal fungi expert Dr. Efrén Cázares, a research scientist at Oregon State University, has observed that more inoculum will survive if the inoculum is spread once the seedling plant has emerged, allowing the mutually beneficial interaction between plant and fungus to begin taking place as soon as possible. This is especially important if there is a significant lag between the time when seed is sown and germination (Cázares and others 2002).

In some instances, it may not be possible to acquire fresh inoculum just before seedling emergence. For instance, plants may be grown in the winter when the project site is under a mantle of snow. According to Cázares, inoculum can be stored in a dormant state at a cold temperature, but not frozen (Cázares and others 2005).

Plants that have been inoculated at the nursery are more likely to thrive than plants that were not. Growing conditions in the nursery will alter the soil flora because the growing conditions and nutrient levels (such as those supplied by fertilizer) are different than in the native plant community. Some nurseries may not want to inoculate seedlings because of the risk of introducing soil pathogens to the nursery. Other nurseries have ways to isolate different plant populations.

Whether plants have been inoculated at the nursery or not, they can be inoculated at the restoration site. Ideally, if you are applying topsoil, you already will be introducing mycorrhizal fungi (and soil bacteria). If it is not feasible to apply topsoil, you can spread a thin layer (about 1 to 2 teaspoons of inoculum) into the root zone of each planting hole. If you are planting seed at the restoration site, it is best to inoculate the seedling plants as soon as they emerge.

The other option is to inoculate the planting site just before seeding. The risk of this approach is that the fungi may die before the seedlings emerge. After the soil is prepared, a thin layer of inoculum is spread over the soil surface, seed is sprinkled on top of the inoculum so that the roots will push through the inoculum when they emerge, and a thin layer of soil is spread on top of the seed (depending on the species). Adding woody materials will benefit fungi by providing a reserve of moisture, as will mulch applied on top of the soil.

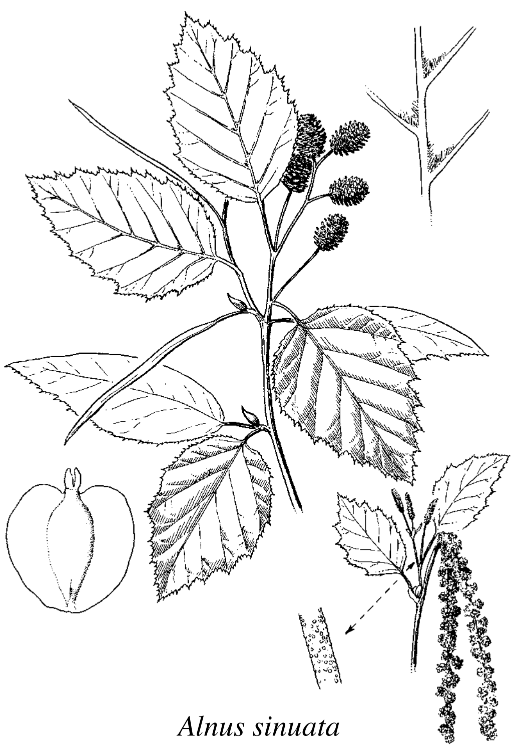
3.2.5c Soil Bacteria

Depending on the environment and the plant species involved, various beneficial bacteria live in the soil and improve growing conditions for plants. The beneficial bacteria include nitrogen-fixing bacteria found in root nodules on some plants, and “free-living” aerobic bacteria found in soil crusts. Free-living bacteria do not live inside a host, as do the nitrogen-fixing bacteria that live in nodules on plant roots or the bacteria that live in the guts of insects. Some anaerobic bacteria thrive in soils saturated by water. These bacteria can be detrimental to root growth and release nitrogen from the soil into the atmosphere.

Nitrogen-Fixing Bacteria

Some types of plants host bacteria that live symbiotically in nodules on the plant's roots. These bacteria thrive by metabolizing sugars supplied by the plant, while converting atmospheric nitrogen that has washed into the soil through rain to a mineralized form that can be used by the plants. Plants that host colonies of nitrogen-fixing bacteria are called nitrogen-fixing plants. Such plants are very important to rebuilding nitrogen in damaged soils. These bacteria, as well as free-living bacteria, are likely to be present in all but the most damaged soils.

The legume or pea family (Fabaceae), the best-known group of nitrogen-fixing plants, is colonized by a bacteria called Rhizobium. Other plants (figure 3–38) host different genera of bacteria, which also may be nitrogen fixers.



Alnus sinuata

Figure 3–38—Alders, once thought of as weedy tree species by foresters, have gained more respect now that their role as nitrogen fixers is understood. *Alnus sinuata*, wavy-leaved alder, has a very sweet fragrance when its leaf buds are opening. It is found throughout mountainous regions in the Pacific Northwest and as far east as the Rocky Mountains of Colorado. Drawings courtesy of the University of Washington Press (Hitchcock and Cronquist 1976).

If a plant is a known nitrogen fixer, inoculation is similar to the method used for mycorrhizal fungi. The inoculum is collected from the same species or group of plants. However, the bacteria are found in visible nodules on the root of the plant. A slurry can be made by blending the roots with water to break open the nodules, releasing the bacteria. This slurry can be used to water nitrogen-fixing plants.

Green materials high in nitrogen (such as alfalfa crumbles) can be mixed into the soil to favor bacteria. Grasslands tend to be dominated by bacteria rather than fungi.

3.2.5d Restoring Soil Crusts

Some soils, especially soils lacking a litter or duff layer (such as arid or alpine soils), form visible microbiotic crusts (see figures 3–24a and 24b, and 3–25).

The restoration of soil crusts (figure 3–39) is an emerging science. Restorationists such as Dr. Jayne Belnap, who works in the arid Southwest, are leading the way. Crusts are easy to pulverize underfoot. It is best not to disturb these crusts because full recovery may take hundreds, if not

Figure 3–39—Biological crusts are recognized easily by their distinct structure. Salvaged crusts can be pulverized before being added back to the surface of restoration sites to inoculate the site.

thousands, of years. However, if soil crust has already been damaged (or damage is unavoidable), it may be wise to stockpile soil crust and use the stockpile to reinoculate the restoration site afterward.

Once a disturbed site in an area with soil crusts has been stabilized, backfilled, and planted, the final step is to broadcast the pulverized crust. The ideal is to replace the crust at a 1:1 ratio with the backfilled material. It is rare to have this much crust material available. A 1:10 or 1:20 ratio of crust to backfill is more common. The pulverized crust material should be no deeper than 1 inch (about 25 millimeters) after it has been spread.

If salvaged soil is to be respread immediately, the crust can be salvaged simultaneously with the topsoil layer to a depth of about 8 inches (about 200 millimeters). The live soil organisms will quickly recolonize the restoration site.

If salvaged soil must be stored before being reused, the top inch (about 25 millimeters) of crust should be removed and stored separately from the remaining 3 to 8 inches (about 80 to 200 millimeters) of topsoil. Salvaged crusts can be stored in an active or dormant state. For the crust to remain active, it must be able to photosynthesize and receive moisture. Spread the crust material just an inch or two thick. For dormant storage, store dry crust material away from moisture and sunlight, for instance, by storing it in buckets with lids. For dormant storage, the material must be dry when stored (Belnap and Furman 1997).

3.2.6 Solarization of Weedy Soils

If a restoration site is plagued by exotic plant species, it may be necessary to treat the soil before seeding or transplanting. Solarization, if done correctly, will kill most plants and seeds in the soil. Solarization, which involves covering the soil with plastic sheeting for 6 to 8 weeks, is most effective with cool-season weed and grass species. The treatment is less effective with deeply rooted summer weeds or plants that spread underground by rhizomes. Rhizomatous plants may require a second treatment, with the ground being rescarified or ripped between the treatments.

A side benefit of solarization is an increase in plant growth rates after treatment. While this effect is poorly understood, decomposition of vegetative matter may increase during solarization, making nutrients more available to plants.

However, the solarization technique kills not only weed seeds, but native seeds and some soil micro-organisms. Because the soil is nearly sterilized, solarization should be used only if the exotic species are invasive and too difficult to remove by other means. This technique also can kill pathogenic fungi, bacteria, and viruses. Interestingly, mycorrhizal fungi and earthworms seem to survive solarization.

The procedure for soil solarization follows Bainbridge (1990). Prepare the site by decompacting the soil or by spreading out salvaged topsoil 6 inches (about 150 millimeters) deep. Make sure the soil is slightly moist by adding up to 1 inch (about 25 millimeters) of water, if needed. At the time of year when weed seeds would be germinating, spread out sheets of clear 0.04- to 0.08-inch- (1- to 2-millimeter-) thick polyethylene sheeting, ideally leaving a slight airspace between the sheeting and the soil. Rocks, sticks, or small bags full of soil can be used to maintain the airspace. For windy sites, sheeting may need to be 0.16 to 0.24 inch (4 to 6 millimeters) thick. Cooler sites may need a double layer of plastic with an airspace between the layers. Bubble-pack material is inexpensive and may be worthy of experimentation. Anchor the sheeting, especially around the edges, to prevent moisture and heat from being lost and to make sure that the wind does not lift it. As an alternative, the edges of the sheeting may be buried.

Leave the sheeting in place for 6 to 8 weeks. Monitor the soil temperature (figure 3–40) using a soil thermometer. Most weed seeds are killed at temperatures of 180 degrees Fahrenheit (about 82 degrees Celsius). Some species may survive to temperatures of 212 degrees Fahrenheit (100 degrees Celsius). Any holes in the sheeting must be patched with clear packaging tape; check for holes by looking for areas where water has not condensed under the plastic. Avoid walking on the sheeting. If it is absolutely necessary to cross the sheeting, wear soft-soled shoes or go barefoot.

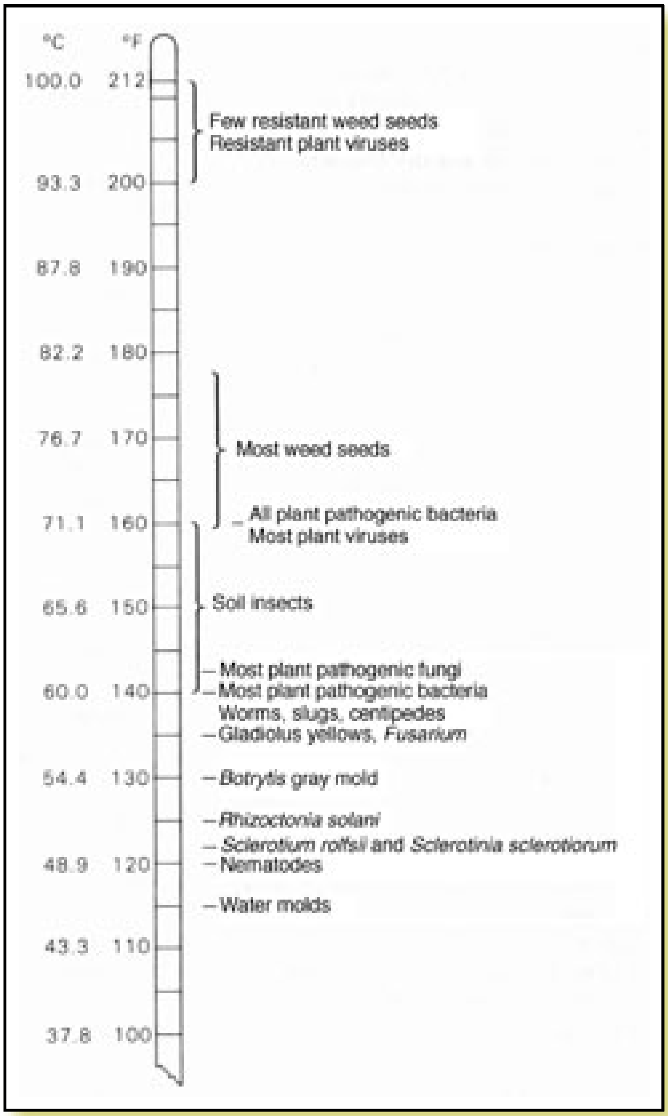


Figure 3–40—This thermometer shows the soil temperatures that will kill weed seeds, insects, and plant pathogens. Temperatures assume heat treatment for 30 minutes under moist soil conditions (Hartmann and others 1990).

Once the soil has been treated, minimize any further disturbance to the top 6 inches (about 150 millimeters) of the soil to prevent bringing viable weed seed deep in the soil to the surface, where it will germinate.

3.3 Concluding Thoughts on Soil

Here are the basic steps to remember when analyzing and working with soil.

- Select a reference site that is representative of the impacted site and that reflects project limitations, including soil limitations.
- Analyze the differences between the site to be treated and one or more reference sites.
- Work with a soil specialist to devise a prescription that will correct as many soil deficits as necessary.
- Use native and local soil sources to the extent possible, without damaging the borrow site.
- Use additional materials or supplements if native sources are not adequate.
- Monitor and maintain your site. If at first you don't succeed, try a different approach.
- Recognize that the process of correcting and rebuilding damaged soils is very slow and difficult, taking many years, if not decades. You should be able to notice the site improving as it becomes more like the desired native plant community.

3.4 Site Stabilization, Preparation, and Delineation

The precise order of actions taken to prepare a site may vary, but generally follows this sequence:

1. Recontour the site if needed.
2. Scarify the soil.
3. Install erosion-control features.
4. Install barriers.
5. Add additional soil needed for fill.

6. Add icebergs and posts for signs, if any are needed to discourage use of the site as it recovers.
7. Add soil amendments and additional organic material.
8. Leave the soil surface uneven (pitted).
9. Install crimping before seeding.

Site stabilization and delineation help create a stable area where native plants can reestablish themselves, given enough time. Your goal may be to further stabilize a relatively flat area (such as a campsite), or to stabilize an unstable slope (such as a steep site or trail slump) or a gully (such as an entrenched trail).

A site-stabilization strategy needs to be designed to handle peak annual waterflows. Peak flows may occur during snowmelt, the rainy season, or heavy thunderstorms.

A number of additional techniques for establishing vegetation and reducing erosion are described in more detail elsewhere in this guide. Such methods include:

- Using mulch and erosion-control blankets—see section 3.12, *Plant Protection and Establishment.*
- Preventing further damage to biological crusts—see section 3.1.3c, *Evaluating Biological Soil Crusts.*
- Inoculating plants with mycorrhizal fungi—see section 3.2.5b, *Inoculating Plants With Mycorrhizal Fungi.*
- Adding organic matter—see section 3.2.3c, *Amending Altered or Depleted Soils.*
- Selecting plant species that provide rapid cover and a variety of root forms—see section 3.10, *Plant Selection, Collection, and Propagation Techniques.*

Site delineation is the process of engineering a site to keep users where you want them. This involves designing visual cues or even physical barriers to concentrate use.

In the mechanical world of industrial-strength restoration, crawler tractors, backhoes, dump trucks, rippers, and imprinters make short work of site preparation. In the wilderness world, we work with modified stock panniers, 5-gallon (19-liter) buckets, stretchers, log carriers, come-alongs, pick axes, shovels, grub hoes, and McLeods—not to mention blood, sweat, and tears. In some areas, helicopters and wheelbarrows have been deemed the minimum tool, moving material more quickly and, in some cases, with less damage than other techniques.

Livestock can haul soil and gravel in specialized panniers (figure 3–41). These panniers are loaded from the top and unloaded from the bottom without removing them from the animal. *Gravel Bags for Packstock* (Vachowski 1995) offers alternative designs, sources, and even a plan for making your own specialized panniers.

Figure 3–41—Fabric bags (panniers) that can be loaded from the top and unloaded by releasing the bottom are handy when stock are used to haul gravel or soil.

3.4.1 Reestablishing Site Contours

Recontouring your site (figures 3–42a and 42b) is likely to be part of a restoration prescription. In an ideal world, a site would be restored to its original contour. However, the fill material needed to achieve such an ambitious goal may not be available. In addition, the slope angle may have become too steep to support successful restoration. A more intermediate set of goals could include: restoring a more natural appearing line, controlling the movement of water through the area to be replanted, and creating a favorable medium for reestablishing vegetation. Meeting such goals may involve rearranging existing site materials or building structures that are backfilled with rock and soil.

Runoff contributes more to erosion than all the trampling hooves and feet on a trail. Methods for evaluating erosion were addressed in the section on assessing soil conditions. Is water channeled into the site causing ongoing damage? Is it desirable to redirect water away from the site or would this cause unacceptable change to slope hydrology? Work with your soil scientist or geologist to address these issues.

For example, digging an uphill parallel ditch (figure 3–43), is a time-tested trail management strategy to dry up muddy trail segments and redirect water across the trail at a natural sag in the grade. This strategy drops the water table, which changes the vegetation on the site. Differing solutions

Figures 3–42a and 42b—This wide, severely eroded trail at Snow Lake in the Alpine Lakes Wilderness, WA (top), was brought back up to grade (bottom) by installing siltbars and adding many buckets of locally collected fill.

Figure 3–43—A small parallel ditch dug alongside this social trail will dry out the tread surface, reducing the likelihood that hikers will walk to the side of the trail, making it wider and wider. The salvaged plugs of plants and soil were transplanted into closed social trails nearby. The plant community may change because the water table will drop to the depth of the parallel ditch.

might come into play. Water can be redirected away from the site, channeled through the site, slowed while being allowed to continue moving through the site, fanned out across the site—or managed using any combination of these techniques. Bioengineering techniques also can be used to reduce excess water on projects (Eubanks and Meadows 2002).

Steep sites may be reworked to eliminate erosion channels by creating a smooth slope with no vertical rills, enabling water to spread out across the slope. Another approach is to harden erosion gullies with a series of structures designed to absorb the impact of flowing water and to trap sediment. Water has to go somewhere; if you don't plan for the flow, it is likely to cause erosion someplace else.

If the top of a steep slope is headcutting, the headcut (figures 3–44a and 44b) must be stabilized by laying back the slope. The headcut is where the slope is eroding the fastest, generally at the top. Where headcutting is occurring under mats of vegetation, it is sometimes possible to excavate underneath the vegetated mat and lay the mat down over the recontoured slope break.

Figure 3–44a—Soil lost because of extensive historical sheep grazing initiated the headcutting shown above, which continues eating into the bank, destroying the integrity of this subalpine meadow in the Alpine Lakes Wilderness, WA.

Figure 3–44b—This roadbank headcut will continue to erode unless it is treated. The slope angle could be reduced by hollowing out the bank from below. The mat of vegetation could be pinned to the soil substrate.

Arid land restorationist and researcher Jayne Belnap recommends recontouring with a 3:1 (33 percent), or shallower slope. She suggests that any slope steeper than 2:1 (50-percent slope) will be too steep to treat successfully (Belnap and Furman 1997). A series of terraces could be created on steeper slopes. In riparian areas, bioengineering techniques could be used.

3.4.2 Stabilizing Gullies

Three mechanisms contribute to the formation of gullies: headcutting, downcutting (erosion that deepens the gully), and lateral cutting into the banks (Prunuske 1987). You need to address all three mechanisms when you are stabilizing erosion in a gully. A deeply incised trail may not have headcutting, but it will be eroding through the other two mechanisms.

3.4.3 Stabilizing Headcuts

A headcut is where a gully is eroding the fastest, generally at the upper end. If a headcut is not treated, it will continue to eat its way upslope (figure 3–45). A bank headcut is found at the top of road or trail cutbanks.

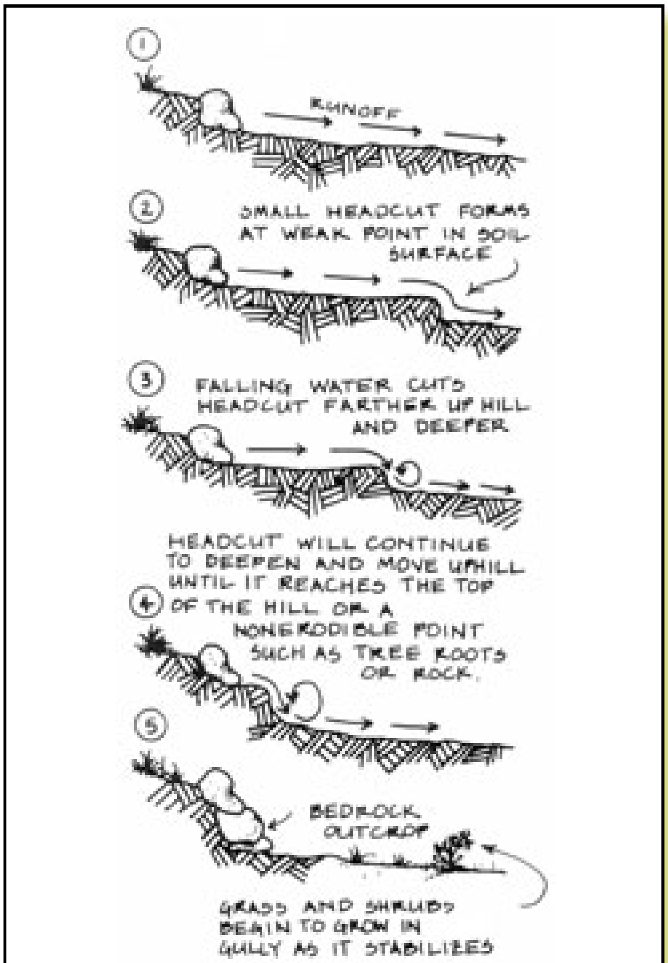


Figure 3–45—The process of gully movement. Drawing courtesy of Susan Pinkerton (Prunuske 1987).

A headcut with low gully erosion and low flow velocities may be treated by reshaping the headwall to a 3:1 or shallower slope (figure 3–46), armoring the slope with rock riprap, or revegetating the slope with herbaceous cover, shrubs, or trees. Moderate gully erosion requires a combination of treatments. Serious gully erosion requires the combination of shaping, rock riprapping, and establishing a variety of plants, including woody plants (Prunuske 1987).

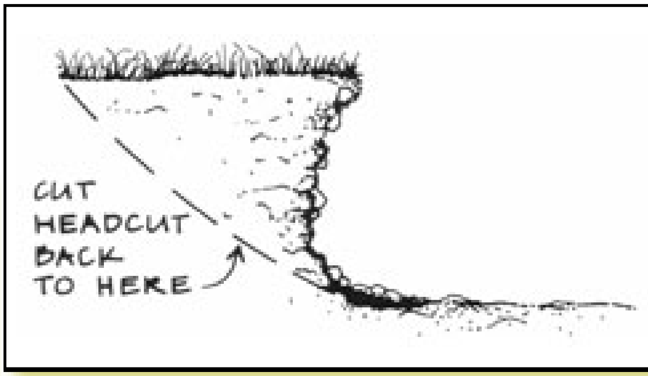


Figure 3–46—The headcut is laid back to a 3:1 slope angle. Drawing courtesy of Liza Prunuske (Prunuske 1987).

3.4.4 Stabilizing Downcutting

Downcutting erodes the gully deeper (figure 3–47), which also drops the water table, changing vegetative characteristics. Downcutting can be slowed by reducing the speed of flowing water and raising the level of the gully. This is accomplished by constructing checkdams, then backfilling the checkdams or allowing adjacent surface erosion to fill the dams. Checkdams are small dams designed to check (stop) erosion, but not to store water. Checkdams that are more than 4 feet (about 1.2 meters) tall need to be designed by an engineer.

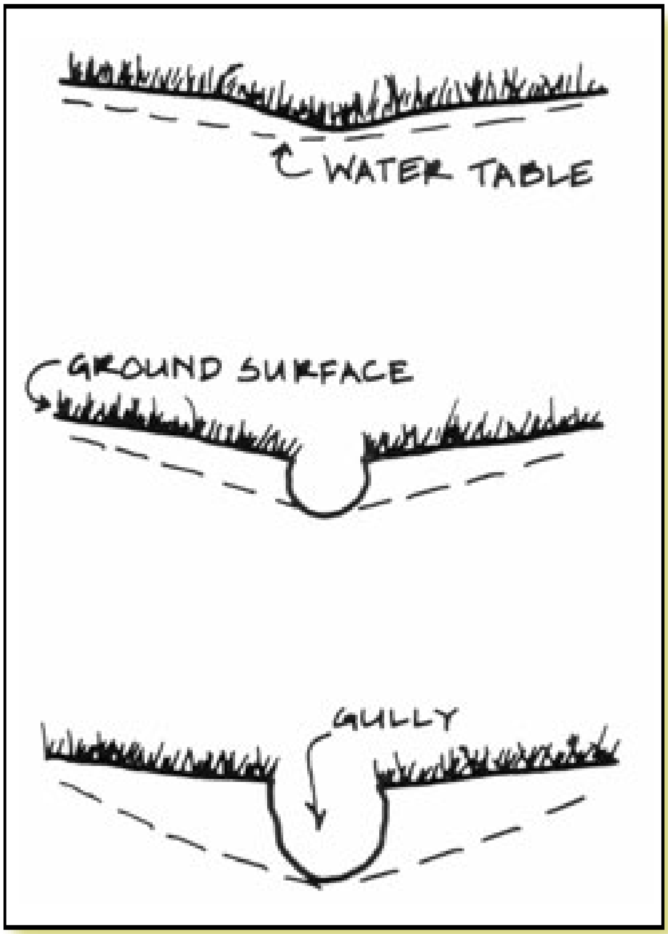


Figure 3–47—Downcutting in gullies not only increases soil lost through erosion, but also drops the groundwater table to the base of the gully. Drawing courtesy of Liza Prunuske (Prunuske 1987).

3.4.5 Stabilizing Lateral Erosion Into Gully Banks

Unless a gully is backfilled completely, its banks should be stabilized with vegetation. If the banks are too steep for vegetation to become established, the banks must be laid back to a shallow angle so plants can grow.

3.4.6 Surface Erosion Control

Riprap (figure 3–48) is a layer of heavy stones laid down to armor the soil surface, preventing further erosion. Riprap also may be used to armor trails, as is commonly the case in the Sierra Nevada Mountains of California and Nevada. Riprap has been used at rather grand scales—such as armoring entire stretches of riverbanks or shorelines. This guide just explores small-scale applications.

Figure 3–48—Riprap reduces surface erosion by providing a durable surface in Grand Canyon National Park, AZ.

The size of the largest rocks used to construct riprap is based on the water velocity at peak flows. Once you have placed the largest rocks, fit smaller rocks between them to construct a stable surface that doesn't wobble underfoot. Refer to tables 3–5 and 3–6 to determine rock weights and the relative proportions of different sizes of rocks.

Table 3–5—Determining the size of riprap (Prunuske 1987).

Water velocity feet per second (meters per second)	Approximate Rock diameter inches (millimeters)	Weight of a rock pounds (kilograms)
2 (0.6)	2 (51)	--
4 (1.2)	4 (102)	--
6 (1.8)	7 (178)	--
8 (2.4)	10 (254)	50 (23)
10 (3.1)	14 (356)	150 (68)
12 (3.7)	19 (483)	375 (170)
14 (4.3)	25 (635)	1,000 (454)
16 (4.9)	33 (838)	2,000 (907)

*This calculation assumes rock weighs 165 pounds per cubic foot (2,643 kilograms per cubic meter). Rock should have a minimum specific gravity of 2.5, meaning a cubic foot (0.028 cubic meter) of rock weighs 2.5 times as much as a cubic foot (0.028 cubic meter) of water.

Before riprap is installed (figure 3–49), a layer of filter material is laid down to prevent piping, a problem that develops when water sluices out of fill material underground. Natural filter materials include gravel or a thick layer of organic leaf litter. A commercial filter fabric can be installed using 6-inch (about 150-millimeter) staples. This option deters establishment of long-rooted plants. Riprap is installed from the base up. A trench is dug at the toe of the slope. Big rocks are keyed into this trench. Then angular rocks are fitted together working up the slope, using intermediate-sized rock to fill spaces between the larger rocks. Plantings can be incorporated between the rocks, if desired. Live stakes, which will sprout into shrubs, can be driven through openings between the rocks (see figure 3–62). During the first few years, areas of riprap where rocks have washed out will need to be patched.

Table 3–6—Determining relative proportions of stone sizes for riprap (Prunuske 1987).

Maximum weight of rock pounds (kilograms)	Minimum and maximum weight of rocks pounds (kilograms)	Weight range of 75 percent of rocks pounds (kilograms)
150 (68)	25 to 150 (11 to 68)	50 to 150 (23 to 68)
200 (91)	25 to 200 (11 to 91)	50 to 200 (23 to 91)
250 (113)	25 to 250 (11 to 113)	50 to 250 (23 to 113)
400 (181)	25 to 400 (11 to 181)	100 to 400 (45 to 181)
600 (272)	25 to 600 (11 to 272)	150 to 600 (68 to 272)
800 (363)	25 to 800 (11 to 363)	200 to 800 (91 to 363)
1,000 (454)	50 to 1,000 (23 to 454)	250 to 1,000 (113 to 454)
1,300 (590)	50 to 1,300 (23 to 590)	325 to 1,300 (147 to 590)
1,600 (726)	50 to 1,600 (23 to 726)	400 to 1,600 (181 to 726)
2,000 (907)	75 to 2,000 (34 to 907)	600 to 2,000 (272 to 907)

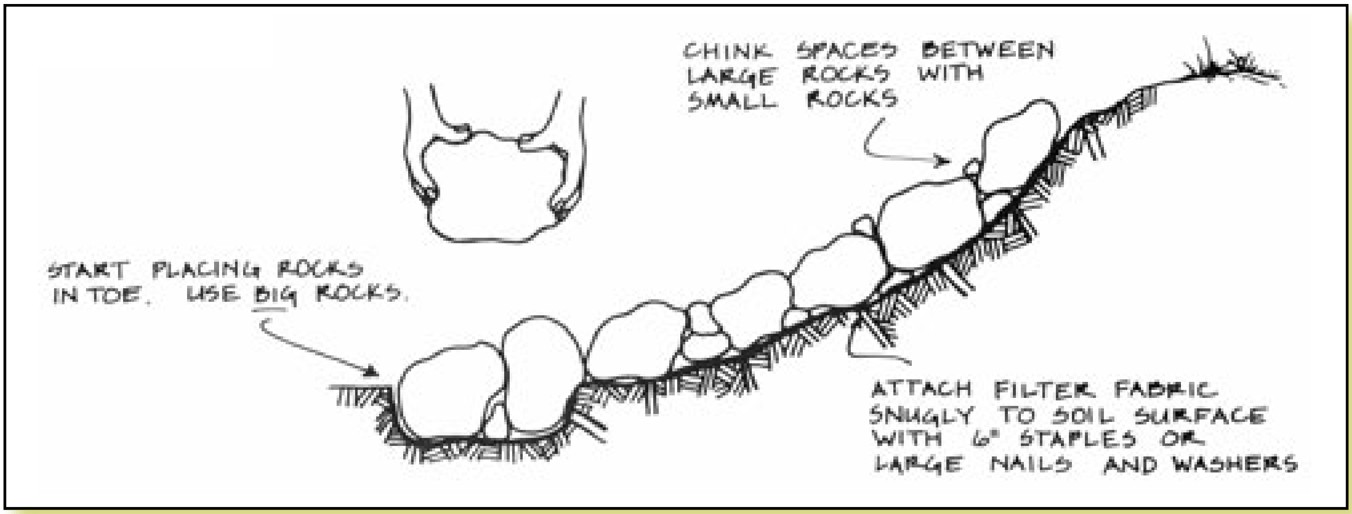


Figure 3–49—Placing rock for riprap. Drawings courtesy of Susan Pinkerton (Prunuske 1987).

3.4.7 Subsurface Erosion Control

In general, structures are installed in the order that creates the least additional disturbance. As much as possible, excavated soil or rock is piled within the existing disturbed area. Another suitable staging area might be located nearby to hold excess fill or salvaged plant materials. Work back toward a hardened "escape route." If possible, work your way downhill to avoid back strain. Training and constant reminders will prevent workers from walking on vegetation adjacent to the site, causing further damage.

Subsurface erosion-control structures fall into two broad categories, living and nonliving. Nonliving structures include siltbars or checkdams built of wood (figure 3–50), rock, or erosion-control blanket. On wet sites, native plant materials can be used to craft a variety of structures, a technique known as bioengineering. The plants not only physically stabilize the site, but also provide a plant community (figure 3–51).

Figure 3–50—Log checkdams are an example of a nonliving subsurface erosion control structure. The checkdams are keyed into the bottom and sides of an eroded hiking trail, preventing further erosion and collecting sediment.

Figure 3–51—The live trench pack stabilizing this gully is one example of a living subsurface erosion control structure (Eubanks and Meadows 2002).

3.4.8 Nonliving Siltbars and Checkdams

Siltbars are shallower than checkdams and are just one layer high. Siltbars are used to address erosion on low-angle slopes. They may be used to control erosion at campsites, on trails that are not too deeply incised, or in areas that don't have enough material for checkdams. Checkdams (sometimes called siltdams) are created by stacking siltbars one on top of another. Crimping, a technique that incorporates straw or native hay into the soil surface, can be used when log or rock checkdams would not be appropriate.

3.4.8a Materials Used To Construct Siltbars and Checkdams

In the wilderness and backcountry, native materials are preferred for siltbars and checkdams, if they can be obtained without further damage to the landscape. Checkdams should be constructed to allow water to percolate through the dam; an impervious checkdam is more likely to blow out during heavy runoff.

Native Rock Siltbars or Checkdams—Native rock, if available, is often the best material for siltdams because of rock's longevity and ability to blend with the environment. As is always the case with native materials, evaluate whether the rock can be collected without causing undue harm to ecological processes or the visual setting. For instance, partially submerged rocks with plants growing around them would be a poor choice for removal—the plants are likely to die once they are exposed and an unsightly hole will be left behind.

Log Siltbars or Checkdams—Log checkdams can be constructed from dead material nearby. Native materials also may be brought in using packstock or helicopters. Cedar rails are a common choice for checkdams in the national parks of the Pacific Northwest.

Dimensional Lumber Siltbars or Checkdams—If you strike out on native material, consider using dimensional lumber such as 2 by 6s or 2 by 8s; such material is more challenging to blend with the wilderness environment. You will also need wooden upright material for attaching planks.

Erosion-Control Blanket Siltbars—Erosion-control blankets can function as a siltbar when the blanket is partially buried and pinned with ridges protruding slightly above the ground surface. This technique has been used successfully in arid lands.

3.4.8b Installation of Checkdams

Siltbars (figure 3–52) and checkdams are installed perpendicular to the flow of water. The direction of flow may be tricky to determine in a sinuous gully. Construct siltbars and checkdams so they are deeper and wider than the opening they are blocking to prevent water from flowing under or around the checkdams.

Siltbars, whether rock or wood, are installed by toeing them into the base of the slope. The sides are anchored into the slope or are anchored with wooden pegs.

Checkdam installation involves more technical considerations. Start by digging a trench 6 inches (about 150 millimeters) deep contouring the slope (or perpendicular to the bed of the trail or gully). For eroded trails, continue the trench up the sidewalls of the gully to form a 6- to 12-inch- (about 150- to 310-millimeter-) deep vertical slot (called a *keyway*) slightly wider than your checkdam material (figures 3–53a and 53b).

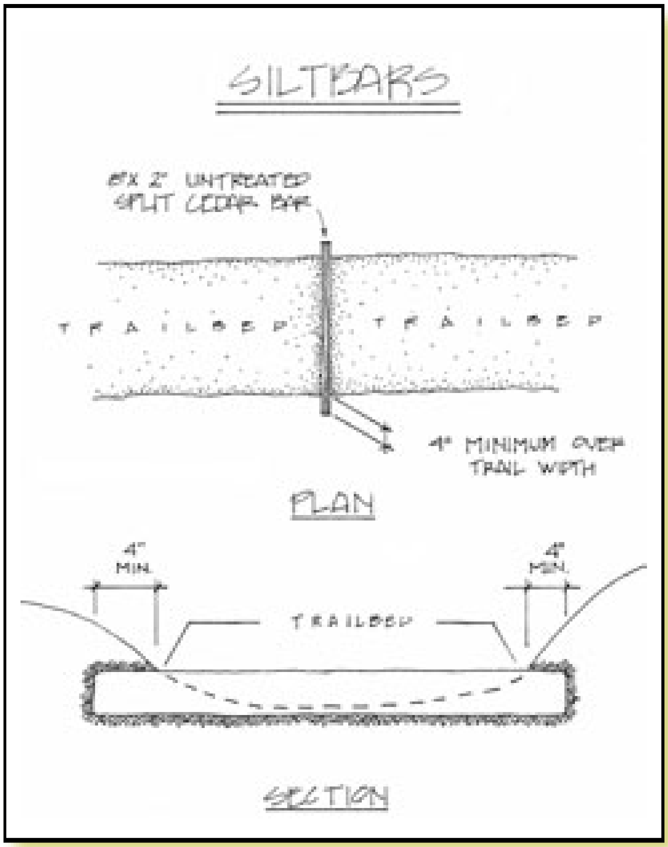


Figure 3–52—Siltbar installation. Siltbars have just one tier of material, unlike checkdams that have more than one tier of material. Drawing courtesy of Regina Rochefort (1990).

Figure 3–53b—In gullies, a keyway is excavated about 6 inches into each sidewall to pin the checkdam or siltbar material into place.

Once the trench has been established, begin fitting in the materials for the siltbar or checkdam. You may need to improve the trench to seat your materials properly. Check your work to assure that the base of the checkdam is well seated, preventing water from flowing under the material. Keep stacking materials until the desired height has been reached—ideally flush with the ground level (figure 3–54). It is not necessary for the top of the checkdam to be above the ground. Keep the checkdam level to avoid channeling water to one side.

Figure 3–53a—To properly seat a siltbar or checkdam, a trench is dug about 6 inches deep across the contour or perpendicular to the gully.

Figure 3–54—Keep stacking materials until the desired height has been reached—ideally flush with the ground level. (This photo has been digitally altered.)

If planks are used for the checkdam, attach them to upright 4 by 4s that have been buried into the bed of the gully to half the depth of the exposed checkdam. The deeply buried uprights prevent the planks from becoming misaligned, which could cause the checkdam to malfunction. Uprights should be about 3 feet (910 millimeters) apart for shorter dams, but no more than 2 feet (610 millimeters) apart for dams that are 3 to 4 feet (0.91 to 1.22 meters) tall (figure 3–55a).

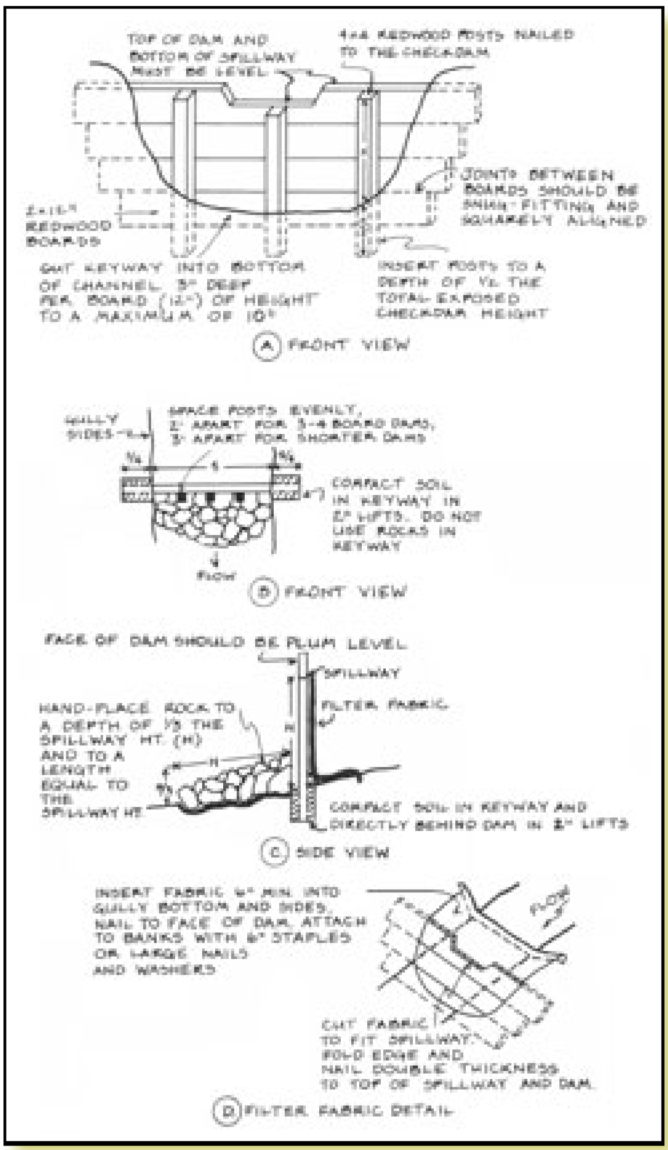


Figure 3–55a—Checkdam installation. Wooden checkdams are constructed by stacking logs or split rails. Drawings courtesy of Liza Prunuske (1987).

Firmly tamp the excavated soil back around the dam. Avoid backfilling the checkdam with rock. Rock backfill could direct water to the dam material, allowing some water to get through.

Rock checkdams (figure 3–55b) also require a trench. Using your very best dry stone masonry skills, select rocks that fit well together to build up a triangular-shaped wall that is broad at the base. Use the same principles you would when building a rock crib. Be sure to stagger the seams between rocks as you add each layer.

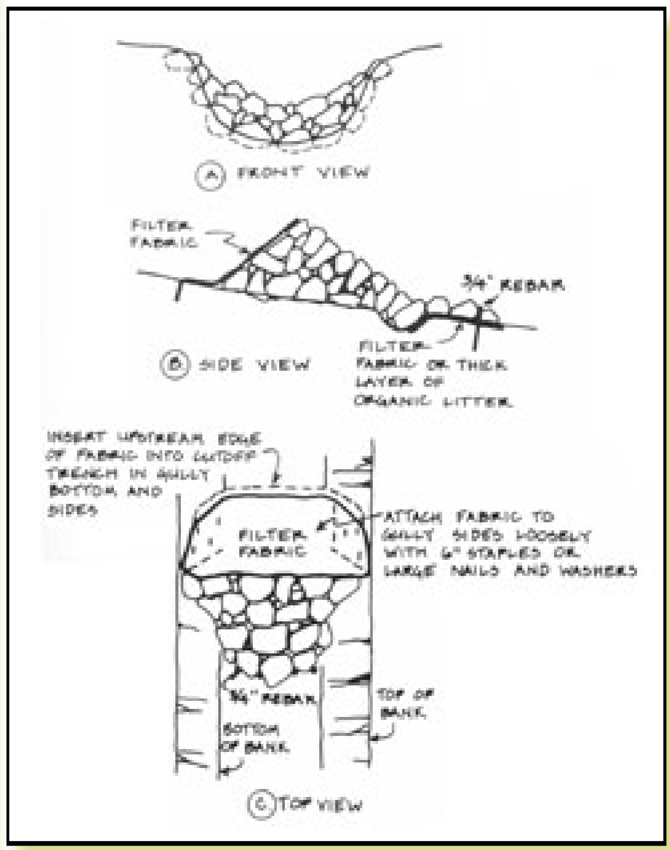


Figure 3–55b—Installing a rock checkdam. Drawings courtesy of Liza Prunuske (1987).

A Rock Checkdam That Worked

A more vertical and less beefy rock checkdam may be adequate if water flows have been redirected elsewhere. One of the authors had good success with this approach at White Pass in the Glacier Peak Wilderness of Washington.

A series of several rock walls were built in an eroded trail that was being closed and restored. A drain dip above the site had directed water off the trail.

Soil and vegetation salvaged from a short relocated trail was placed between the checkdams. The vegetation quickly became reestablished.

Five years later, the only real evidence of the project was the lowest checkdam (figure 3–56), which was serving as a small rock retaining wall.

Figure 3–56—Five years later, the only real evidence of the project was the lowest checkdam.

Perhaps you successfully redirected water off the trail or gully alignment before building the checkdam. But if you are engineering your installation to handle the continued flow of water, three more components are needed for each checkdam—a spillway, an apron just below the dam that serves to dissipate energy, and a filter behind the dam to prevent soil loss while allowing water to continue to flow.

The spillway is a depression in the center of each checkdam to keep water from eating out the banks. Use table 3–7 to determine the size for each spillway. If your checkdam is constructed of wood, make sure the plank or log is still 4 inches (about 100 millimeters) high at the spillway. Otherwise, the plank or log may break. A rock checkdam should have a dip in the center to function as a spillway.

Table 3–7—Spillway width and depth for checkdams (from Prunuske 1987).

Area in acres of gully watershed (hectares)	Depth in inches of a 12-in- (310-mm-) wide spillway (mm)	Depth in inches of an 18-in- (460-mm-) wide spillway (mm)	Depth in inches of a 24-in- (610-mm-) wide spillway (mm)	Depth in inches of a 36-in- (910-mm-) wide spillway (mm)
1 (25.4)	6 (152.4)	4 (101.6)	3 (76.2)	3 (76.2)
2 (50.8)	9 (228.6)	7 (177.8)	5 (127.0)	4 (101.6)
3 (76.2)	12 (304.8)	8 (203.2)	7 (177.8)	5 (127.0)
4 (101.6)	--	10 (254.0)	8 (203.2)	6 (152.4)
5 (127.0)	--	12 (304.8)	10 (254.0)	7 (177.8)

Apron Installation—While the spillway directs the flow of water down the center of the gully, the apron protects the gully and checkdam from the force of the falling water, (figure 3–57). Aprons generally are constructed of rock, but a live fascine (a bundle of live woody stems that will sprout) also could be anchored in the gully. The use of live fascines is explained in the bioengineering section. A filter is laid below the rock apron using techniques described for riprap. Rock is secured across the gully bottom in a low-angle wedge against the downstream side of the checkdam for at least 2 feet (610 millimeters) below the checkdam. If the waterflow is expected to be high velocity, wooden pegs, live stakes, or pieces of ¾-inch (about 19-millimeter) rebar are pounded into the gully bed to pin the lowest course of rock in place.

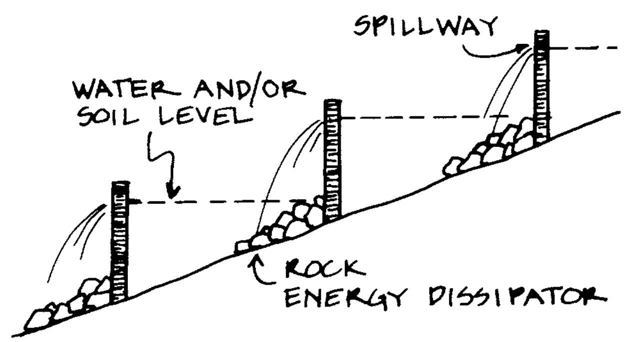


Figure 3–57—A profile of checkdams with aprons, also called rock energy dissipators. Drawing courtesy of Liza Prunuske (1987).

Filter Behind the Dam—Unless you anticipate low volumes of water or a large amount of leaf litter is likely to wash downstream, the final step before backfilling is to install a filter upstream from the checkdam. This measure is to prevent soil from washing through any cracks in the dam. A 6-inch (about 150-millimeter) layer of organic leaf litter can form the filter. Or you can install filter fabric. If you use fabric, it should be laid out loosely so that it won't pull out with the force of the water. The upstream side of the fabric is secured to the gully bed and banks by digging a trench, anchoring the fabric with 6-inch (about 150-millimeter) staples, then refilling the trench. The 6-inch (about 150-millimeter) staples also secure the loose fabric on the remainder of the bottom and sides. Refer to figure 3–55a or 3–55b for an installation diagram.

Checkdam Placement—In long gullies, checkdams are placed in a stairstep fashion. Ideally, the top of the downhill dam is as high as the bottom of the next dam upslope. This standard may not be feasible on steeper slopes. Maintain a 3:1 slope between checkdams, if necessary.

Sometimes it is necessary to segment siltbars or checkdams. For instance, if a site has lots of submerged rock, making it difficult to dig a continuous trench, it may be necessary to toe a siltbar into the rock, and then continue on the other side (figures 3–58a and 58b). Use pegs to secure the siltbar near the rock. A mallet or small sledge hammer is the best tool for driving pegs (figures 3–59a and 59b). You may need to use a small block of wood on top of the peg to avoid splitting it while pounding.

Figures 3–58a and 58b—This trail was as wide as a road at Snow Lake in the Alpine Lakes Wilderness, WA. A huge mantle of soil had been lost, making it infeasible to return the swale to its original contour. Instead, a series of smaller siltbars, comprised of rocks, logs, and split rails, were installed (top) wherever they could be toed in successfully. Topsoil was added behind each checkdam and seedlings grown in a greenhouse were planted. Ten years later (bottom), the erosion had stabilized and vegetation was thriving.

Figures 3–59a and 59b—Stout pegs are shaped with an ax or hatchet (top) and pounded into place with a sledge hammer (bottom). (This photo was digitally altered.)

Once all dams have been installed, fill material can be added. If possible, avoid walking on undamaged vegetation. If reconstructing a soil profile as described in the soils section, add the fill material in the correct order, saving the organic layer for last. If you will be adding rock in the bottom of the trench, be sure to mix in finer materials, such as gravel and soil, to prevent water from washing out the fill material. Assume that the fill material will settle some. If your goal is to completely refill an eroded site, keep adding fill until the checkdams or siltbars are no longer visible.

Rather than smoothing out fill, leave rough mounds and a rough soil surface with small depressions, called pitting, to help control erosion and help plants become established. The pits help catch water, improving seedling survival. In addition, the pits provide some protection from wind and sun.

3.4.8c Crimping

Crimping, also called spiking, incorporates straw or native hay into the soil surface. Crimping helps reduce erosion by slowing and deflecting water. In situations where log or rock checkdams would be inappropriate because of a lack of materials or their unnatural appearance, crimping may be a good option. Crimping also improves water infiltration.

In wilderness, native hay harvested onsite might be an option for material to crimp into the soil. Tall grasses, sedges, or fibrous forbs could be harvested with a scythe. If this is not an option, clean straw, certified weed free or purchased from a known reliable grower, could be used. If available, rice straw is an excellent choice for dry land projects because the water weeds associated with rice culture will not survive on dry land. Rice grown in the Central Valley of California is used extensively for arid land restoration projects.

3.4.9 Bioengineering Applications

Bioengineering offers promise for sites on streambanks, lakeshores, or other wet areas. A bioengineered structure not only will stabilize erosion, but will simultaneously provide living plant material, helping to return the site to a stable, ecologically productive state (figure 3–60). Bioengineering can reduce the need to build structures such as rock gabions, riprap, or terraces that are unattractive and make it difficult to establish vegetation. This guide will provide a few basic bioengineering techniques and concepts that apply to small remote sites. If your project includes extensive or complex riparian habitat, refer to *A Soil Bioengineering Guide for Streambank and Lakeshore Stabilization* (Eubanks and Meadows 2002), which explains in detail how to plan and implement riparian projects.

Figure 3–60—A live post, installed where there is adequate soil moisture, will root and sprout to become a tree or shrub (Eubanks and Meadows 2002).

Bioengineering applies many of the principles of restoration discussed elsewhere in this guide, such as how to assess slope stability, how to choose and handle plant species, and how to work with soil. A few considerations more specific to successful bioengineering applications are outlined here (Potash and Aubry 1997).

Remember to have a clear understanding of the situation you are treating in wilderness. Bioengineering generally is used to address slope and bank failures, often due to human disturbances such as impoundments. Bioengineering applications can be integrated into the construction of trail crib walls to strengthen the trail. Wilderness restoration projects rarely seek to restore a natural slope failure unless private property values are at risk.

Geology, Soils, and Hydrology

The hydrologist, geologist, or geomorphologist on your team should help with the site assessment and project design. Geologic history, types of sediment deposits, evidence of past slides, and soil type and depth are taken into consideration.

Excess water needs to be drained or diverted away from the project. Drainage patterns are noted and the possibilities for redirecting the flow of water are assessed.

Backfill material must allow for free drainage; coarse-grained granular material is best. It should have enough fines and organic material to support the selected plant species. However, the system's design also must take structural strength into account.

A bioengineering treatment will fail unless the cause of the damage has been addressed. For example, a steep undercut or a slumping bank requires earthwork to remove the slope overhang and round the slope for stability. With bank erosion, the toe of the slope is often compromised. Treatment methods must anchor the toe of the structure with rock, root wads, or rolled mat logs.

Vegetation Used for Bioengineering

Limit the removal of existing vegetation at the project site. Tree and shrubby plant species used for bioengineering are selected for their ability to resprout from cuttings, develop strong root systems, and survive in a riparian environment with floods, slides, and erosion. Selecting plants with a variety of root structures will help stabilize slopes (see section 3.10.2, *Plant Selection for Restoration Projects*). Table 3–8 lists a number of plant species well suited to bioengineering applications in the Western United States, based on the criteria that they root readily.

Generally, the plant materials used to build structures are gathered as cuttings from local sources (see section 3.10.1, *Genetic Considerations for Restoration Projects*). Take advantage of any opportunities to salvage plant material from nearby projects, such as trail relocations. Cuttings are best collected in the fall at the onset of plant dormancy, in the winter as long as the ground remains unfrozen, or in the early spring before dormancy is broken. Refer to the section on plant propagation techniques for proper handling of cuttings. Additional plants, such as sedges or forbs, may be incorporated into plantings. Often, these plantings are grown ahead of time in a greenhouse. The use of transplanted wildlings or direct seeding also may be incorporated into plantings.

Ideally, the project will be implemented during the fall, winter, or spring when the plant material can be collected fresh in its dormant stage. If this timing is not feasible, it may be necessary to use rooted cuttings, raising project costs.

Table 3–8—Riparian plant species of the Western United States that are effective in bioengineering applications (Eubanks and Meadows 2002).

Scientific name	Common name	Root structure
Acer circinatum	Vine maple	Fibrous, rooting at nodes
Baccharis glutinosa	Seepwillow	Deep and wide spreading, fibrous
Baccharis pilularis	Coyote brush	Fibrous
Baccharis salicifolia	Water wally	Deep and wide spreading, fibrous
Baccharis viminea	Mulefat baccharis	Fibrous
Cephalanthus occidentalis	Button bush	
Cornus sericea ssp. *sericea*	Redosier dogwood	Shallow
Lonicera involucrata	Black twinberry	Fibrous and shallow
Physocarpus capitatus	Pacific ninebark	Shallow, lateral
Populus angustifolia	Narrowleaf cottonwood	Shallow
Populus balsamifera	Balsam popular	Deep, fibrous
Populus deltoides	Eastern cottonwood	Shallow, fibrous, suckering
Populus fremontii	Fremont dogwood	Shallow, fibrous
Populus trichocarpa	Black cottonwood	Deep and wide spreading, fibrous
Rosa gymnocarpa	Baldhip rose	
Rosa nutkana	Nootka rose	
Rubus idaeus ssp. *strigosus*	Red raspberry	Fibrous
Rubus spectabilis	Salmonberry	Fibrous
Salix ssp.	Willow species	
Sambucus cerulea ssp. *mexicana*	Mexican elder	
Sambucus racemosa	Red elderberry	
Spirea douglasii	Douglas spirea	Fibrous, suckering
Symphoricarpos albus	Snowberry	Shallow, fibrous, freely suckering
Viburnum lentago	Nannyberry	

3.4.9a Selecting and Installing Bioengineered Structures

The structures included in this section are just a small sample of those that are available. These structures were chosen for their appropriateness and ease of application in the wilderness setting. Their descriptions were excerpted from *A Soil Bioengineering Guide for Streambank and Lakeshore Stabilization* (Eubanks and Meadows 2002). That report describes 24 structures that can be used alone or in combinations to address a wide variety of impacts. Refer to their report if your project involves a complex situation. The information excerpted in this guide is for treating small problems. The final structure included in this section, the woven checkdam, is from *Groundwork: A Handbook for Erosion Control in Northern Coastal California* (1987), by Liza Prunuske.

Tools and Supplies for Installing Bioengineered Structures

Loppers (to cut plant stems)

Hand pruners (to trim branches)

Pruning saws (to cut live posts)

Untreated twine (to tie cuttings into bundles)

Burlap bags moistened and lined with wet leaves or mulch (to protect cuttings)

Grub hoe (to dig trenches or reshape slopes)

McLeod rake (to grub, reshape, or rake)

Shovel (to dig holes and salvage plants)

Small sledgehammer or mallet (to drive stakes)

Small blocks of wood (to protect the top of live stakes when they are being pounded)

36-inch (about 910-millimeter) pieces of rebar (to drive pilot holes)

Chisel-tipped pry bar (to open a pilot hole in softer soils)

Dead stout stakes (to secure structures, figure 3–61 and table 3–9)

Crosscut saw or chain saw (to construct live cribwall)

Spikes (to secure cribwall members)

Erosion-control blankets, such as coconut-fiber matting (to build structures or cover loose slopes)

Come-along and chokers (to manipulate large logs)

Log carriers (to transport smaller logs)

Seed spreader (to distribute native seed)

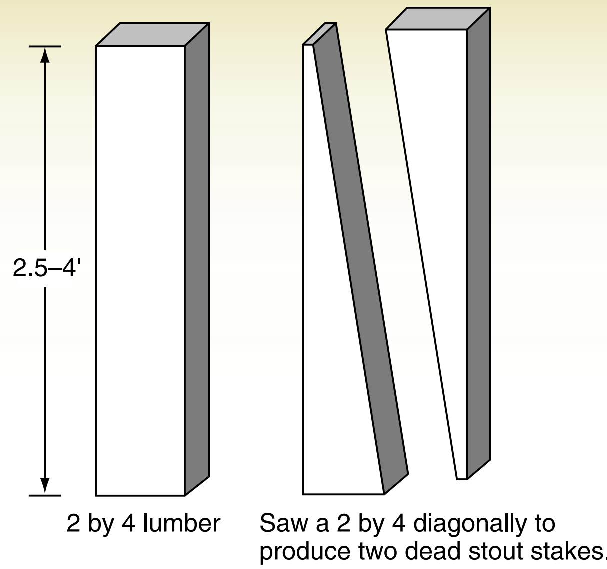


Figure 3–61—Dead stout stakes, cut from 2 by 4s (about 50 by 100 millimeters), are used in many soil bioengineering techniques to anchor branches or erosion control blankets, and to anchor erosion control blanket logs to the bank. (Eubanks and Meadows 2002).

Table 3–9—Recommended lengths of stakes.

Soil type	Stake length	
	Feet	Meters
Clay	2.5	0.76
Silt	3.0	0.91
Sand	4.0	1.22
Loam	2.5	0.76

Live Stakes

Live stakes (figure 3–62) create a living root mat that stabilizes the soil by reinforcing it and extracting excess moisture. Most willow species develop roots rapidly and begin drying out excessively wet banks soon after the willows have been planted. Live, vegetative cuttings that can be rooted are inserted or tamped into the ground. If a live stake is prepared, handled, and placed correctly, it will root and grow.

Applications for Live Stakes

Use stakes in the wetted zone of banks or where precipitation is likely to keep the soil moist during growing seasons.

Live stakes can:

- Be used where site conditions are uncomplicated, construction time is limited, and an inexpensive method of stabilization is needed.
- Repair small earth slips and slumps that get wet frequently.

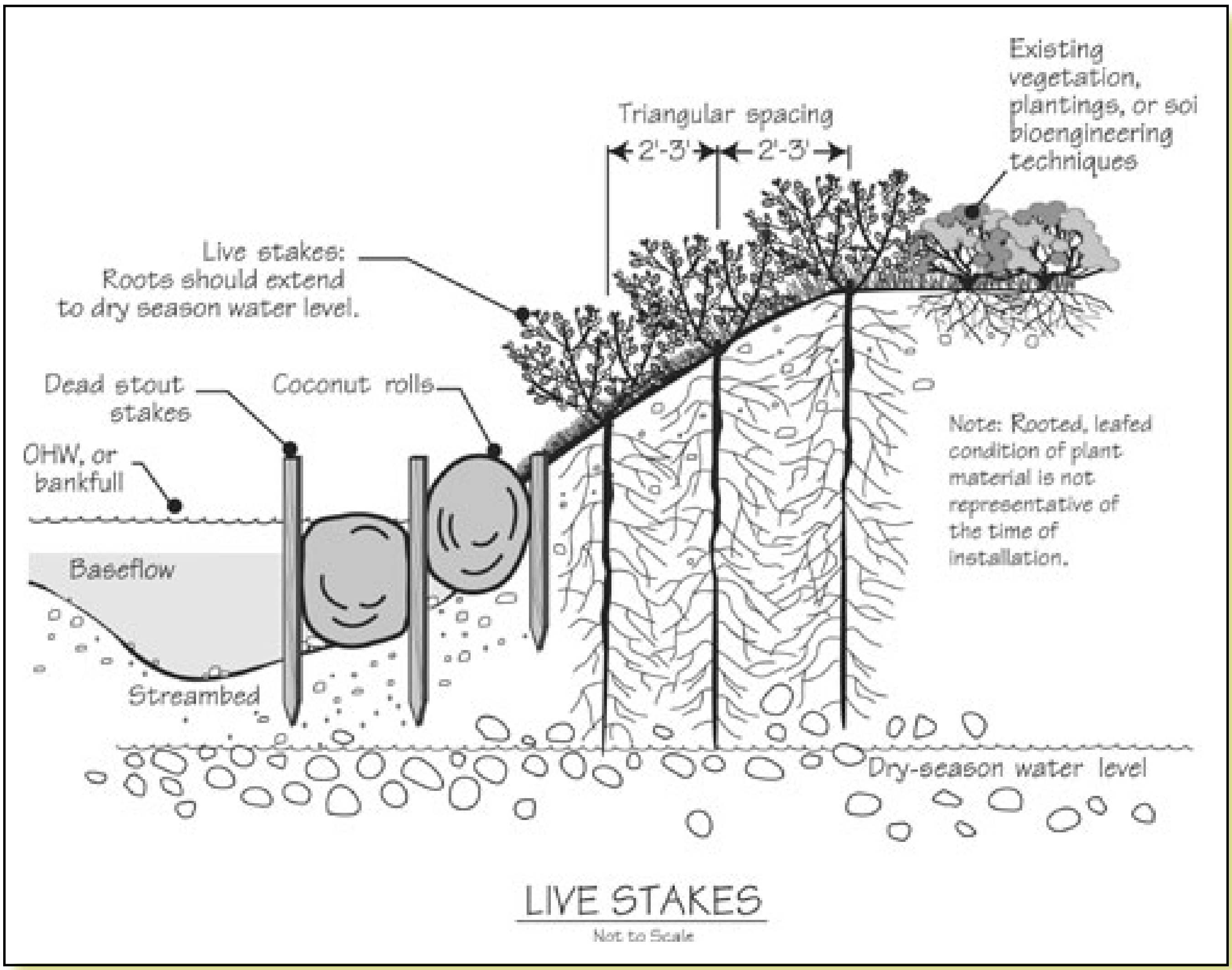


Figure 3–62—Live stakes create a living root mat (Eubanks and Meadows 2002). *OHW* stands for ordinary high water.

- Enhance the performance of geotextile fabric by serving as pegs to hold the fabric down.
- Enhance conditions for natural colonization of vegetation from the surrounding plant community.
- Produce streamside habitat.
- Be used with other bioengineering techniques, such as live fascines (long bundles of branch cuttings).

Materials for Live Stakes

The stakes generally are 1 to 2 inches (about 25 to 51 millimeters) in diameter and 2 to 3 feet (610 to 910 millimeters) long. The specific site requirements and available sources of cuttings will determine the sizes.

- Remove the side branches, leaving the bark intact.
- Cut the basal ends at an angle or a point so they can be inserted into the soil easily. The top should be cut square.
- Install materials the same day that they are prepared.
- Place stakes in locations that are appropriate for the particular species. For example, along many western streams, tree-type willow species are placed on the inside curves of point bars where they are likely to be inundated, while shrub-type willow species are planted on the outside curves of point bars where they are not likely to be inundated as long.

Installing Live Stakes

- Insert stakes with the buds up.
- Install live stakes 2 to 3 feet (610 to 910 millimeters) apart, using triangular spacing. The density of the installation will range from two to four stakes per square yard. Site variations may require slightly different spacing. The spacing pattern should allow for a fluctuating water level. The installation may be started at any point on the slope face.
- Install four-fifths of the length of the live stake into the ground and firmly pack the soil around the stake after installation.
- Remove and replace any stakes that split during installation.
- In firm soil, use an iron bar to make a pilot hole (Hoag and others 2001).
- Dig in live stakes unless the soil is fine and loose. Tamped-in stakes are likely to split or have their bark damaged by hammering or by the hard, rocky soils they're driven into.
- Install the live stake at an angle slightly downstream.
- Tamp the stake into the ground with a dead-blow hammer (head is filled with shot or sand).
- Install geotextile fabric (optional) on slopes subject to erosion. Install the stakes through the fabric.
- Plant stakes on banks that will be moist during the growing season or install longer stakes that will reach the water level during the dry season.

Live stakes do not increase soil stability until they begin rooting. Over time, they provide excellent soil reinforcement. To reduce the possibility that a bank might fail before the roots establish themselves, cover installations with a layer of long straw mulch topped with jute mesh or, in more critical areas, a geotextile fabric.

Live Posts

Live posts (figure 3–63) form a permeable revetment (retaining wall). They reduce stream velocities, allowing sediment to be deposited in the treated area. Their roots help to stabilize the bank. Dormant posts are made of large cuttings installed in streambanks in square or triangular patterns (see figure 3–60). Posts at spacings of about 4 feet (1.2 meters) also can provide some benefits by deflecting higher streamflows and trapping sediment, even if the posts do not root successfully.

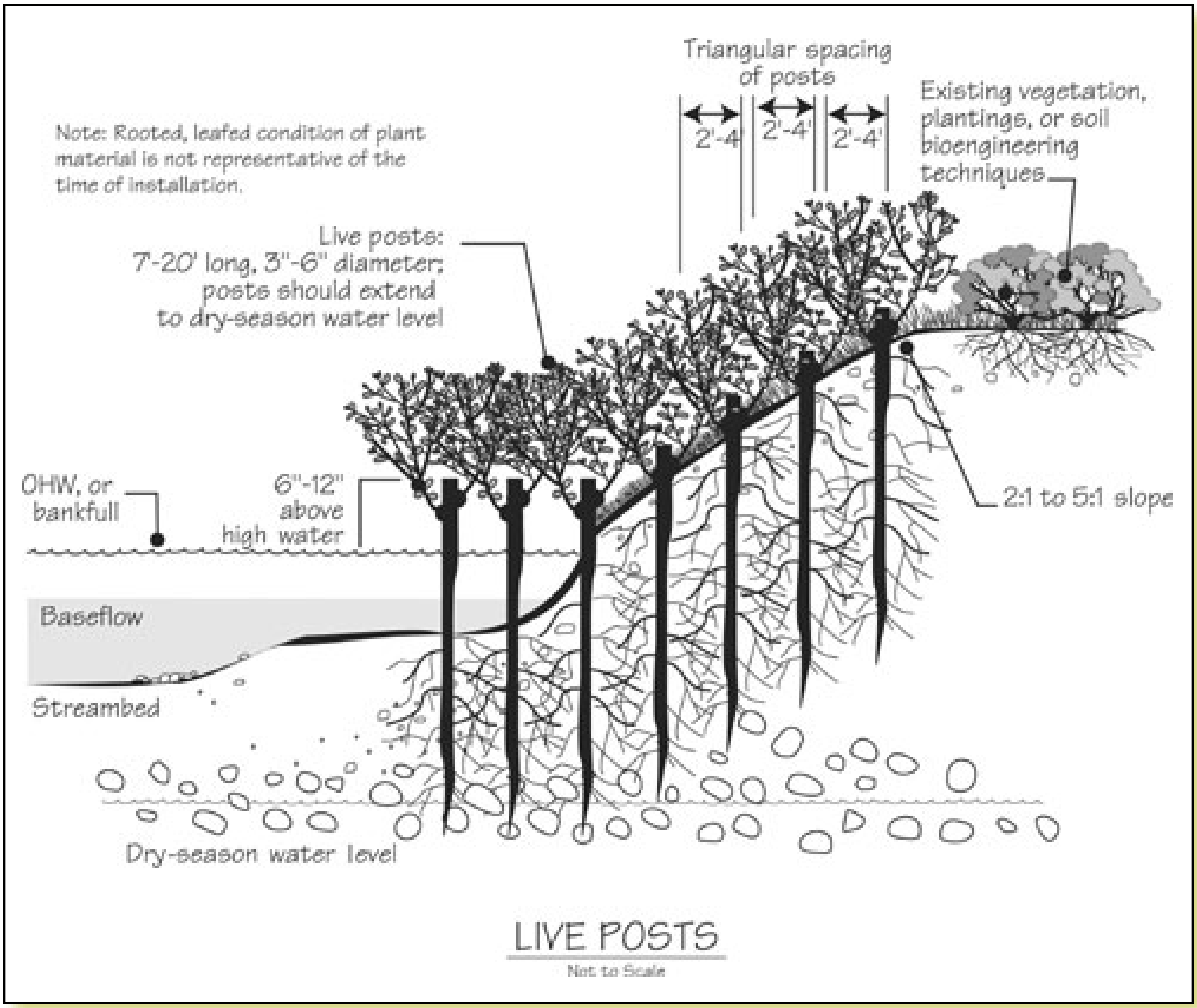


Figure 3–63—Live posts reduce stream velocities, allowing sediment to be deposited (Eubanks and Meadows 2002). *OHW* stands for ordinary high water.

Applications for Live Posts

Live posts:

- Are well-suited to smaller streams that do not have a lot of gravel. If high flows and ice are a problem, posts can be cut low to the ground.
- Can be used with other soil bioengineering techniques.
- Can be installed by a variety of methods, including using a waterjet stinger (Hoag and others 2001) to form planting holes or by driving the posts directly with machine-mounted rams. Place a metal cap on top of the post when it is being pounded into the ground.

Effectiveness of Live Posts

Live posts:

- Quickly reestablish riparian vegetation.
- Enhance conditions for colonization by native species.
- Repair themselves. For example, posts damaged by beavers often develop multiple stems.

Materials for Live Posts

Live posts can be from 7 to 20 feet (2 to 6 meters) long and from 3 to 6 inches (about 76 to 152 millimeters) in diameter. Avoid overharvesting posts from one plant or one area. Select a plant species that will root readily and that is appropriate to the site conditions. Willow and poplar posts have been successful.

Installing Live Posts

- Taper the bottom end of the post so it will be easier to insert into the ground.
- Trim off all the side branches and the apical (top) bud.
- Dip the top end of the post into a mixture of equal parts of water and white latex paint. The paint helps mark the end that goes up and helps retain moisture in the post after it has been installed.

Brush Layering

Brush layering is the technique of laying cuttings on horizontal benches that follow the contour of an existing or filled bank (slope). Brush layers provide shallow stability for slopes.

The cuttings are oriented more or less perpendicular to the slope face as shown in figures 3–64, 3–65, and 3–66. The portion of the brush that protrudes from the slope face helps slow runoff and reduce surface erosion. When brush layering is used on a fill slope, it is similar to the use of vegetated geogrids without the geotextile fabric.

Brush layering does not work on the outside of bends and may direct current between the brush layers, washing out the soil there.

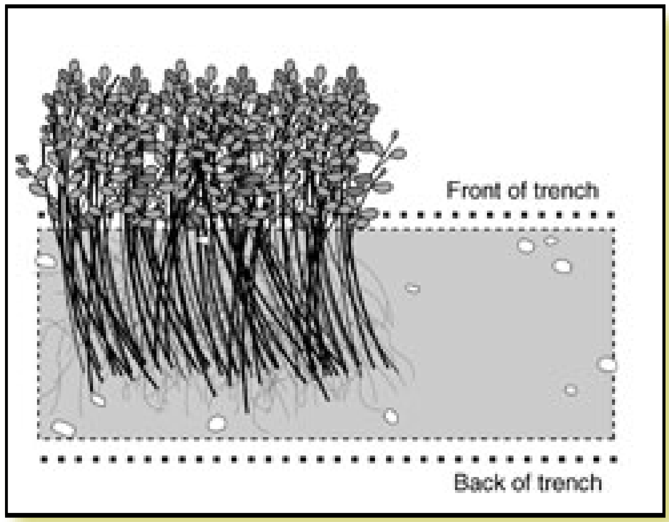


Figure 3–64—With brush layering, live branches are inserted into trenches roughly perpendicular to the slope. Normally, dormant branches are used. They are shown here with leaves so it is clear how the branches are oriented (Eubanks and Meadows 2002).

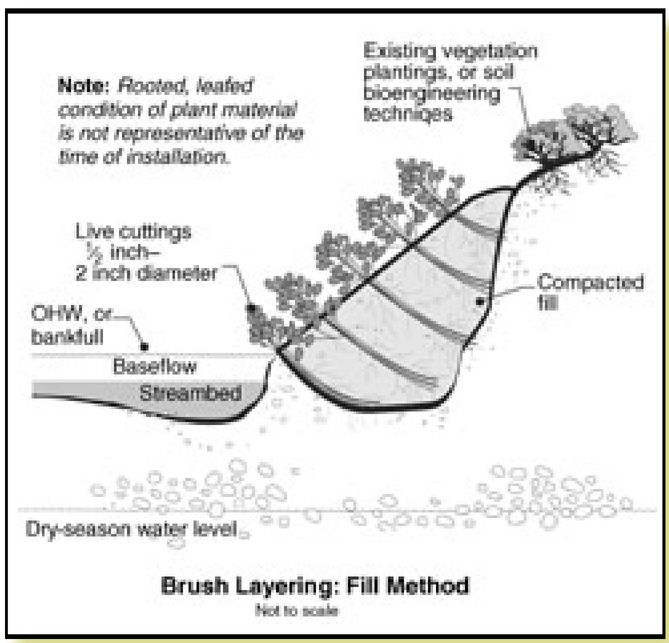


Figure 3–65—This cutaway view shows branches laid into trenches that contour the slope (Eubanks and Meadows 2002). *OHW* stands for ordinary high water.

Figure 3–66—Brush layering can be used to repair an alcove where the bank has washed away (Eubanks and Meadows 2002).

Applications for Brush Layering and Their Effectiveness

Brush layering:

- Breaks up the slope into a series of shorter slopes separated by rows of brush layers.
- Dries excessively wet sites.
- Works where the toe of the slope is not disturbed.
- Works on a slump and as a patch.
- Reinforces the soil with the unrooted branch stems.
- Reinforces the soil as roots develop, adding significant resistance to prevent the soil from sliding or experiencing shear displacement.
- Traps debris on the slope.
- Aids infiltration on dry sites.
- Adjusts the site's microclimate, aiding seed germination and natural regeneration.
- Can be used to treat a gully (figure 3–67).

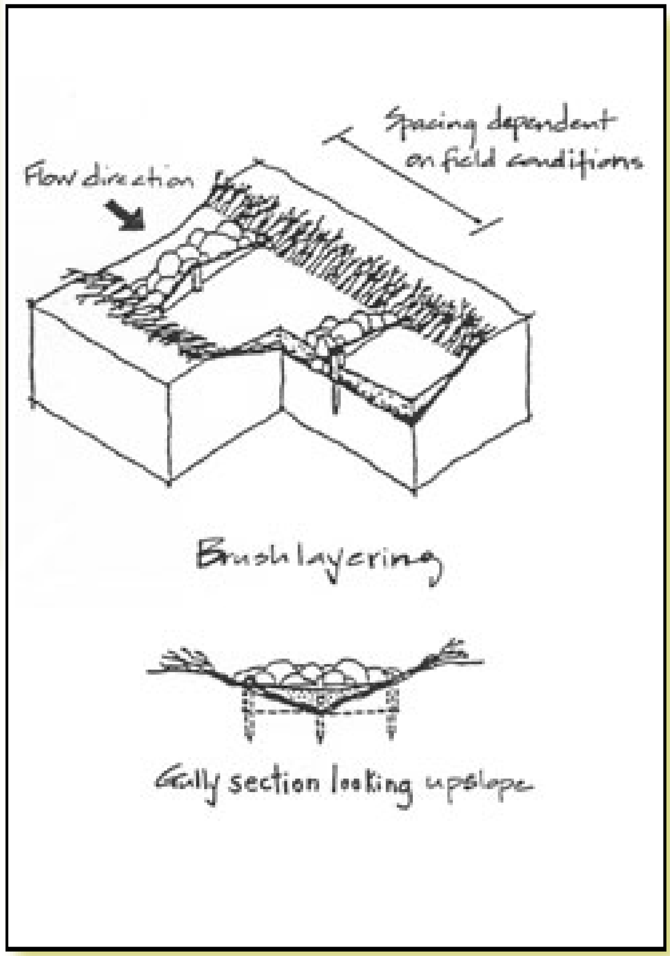


Figure 3–67—A gully can be treated with brush layering. Drawings courtesy of Lisa Lewis (Lewis and Ogg 1996).

Installing Brush Layering

Brush layering can be installed on an existing or filled slope. On an existing slope, a bench is cut 2 to 3 feet (610 to 910 millimeters) deep and angled slightly down into the slope. On a fillslope, brush layers are laid into the bank as it is filled.

Live Cribwalls

A live cribwall is used to rebuild a bank that is nearly vertical (figure 3–68). The cribwall consists of a boxlike interlocking arrangement of untreated log or timber members. The structure is filled with rock at the bottom and with soil beginning at the ordinary high-water mark or water level when the stream is bankfull. Layers of live branch cuttings root inside the crib structure and extend into the slope. Once the live cuttings root and become established, vegetation gradually takes over the structural functions of the wood members. Live cribwalls should be tilted back if the system is built on an evenly sloped surface.

Applications for Live Cribwalls

Live cribwalls are:

- Appropriate at the base of a slope where a low wall may be required to stabilize the toe of the slope and to reduce its steepness.
- Appropriate above and below the water level where stable streambeds exist.
- Useful where space is limited and a more vertical structure is required.
- Useful in maintaining a natural streambank appearance.
- Useful for controlling bank erosion on fast-flowing streams.

Effectiveness of Live Cribwalls

Live cribwalls are:

- Complex and expensive.
- Effective on the outside bends of streams where currents are strong.
- Effective in locations where an eroding bank may eventually form a split channel.

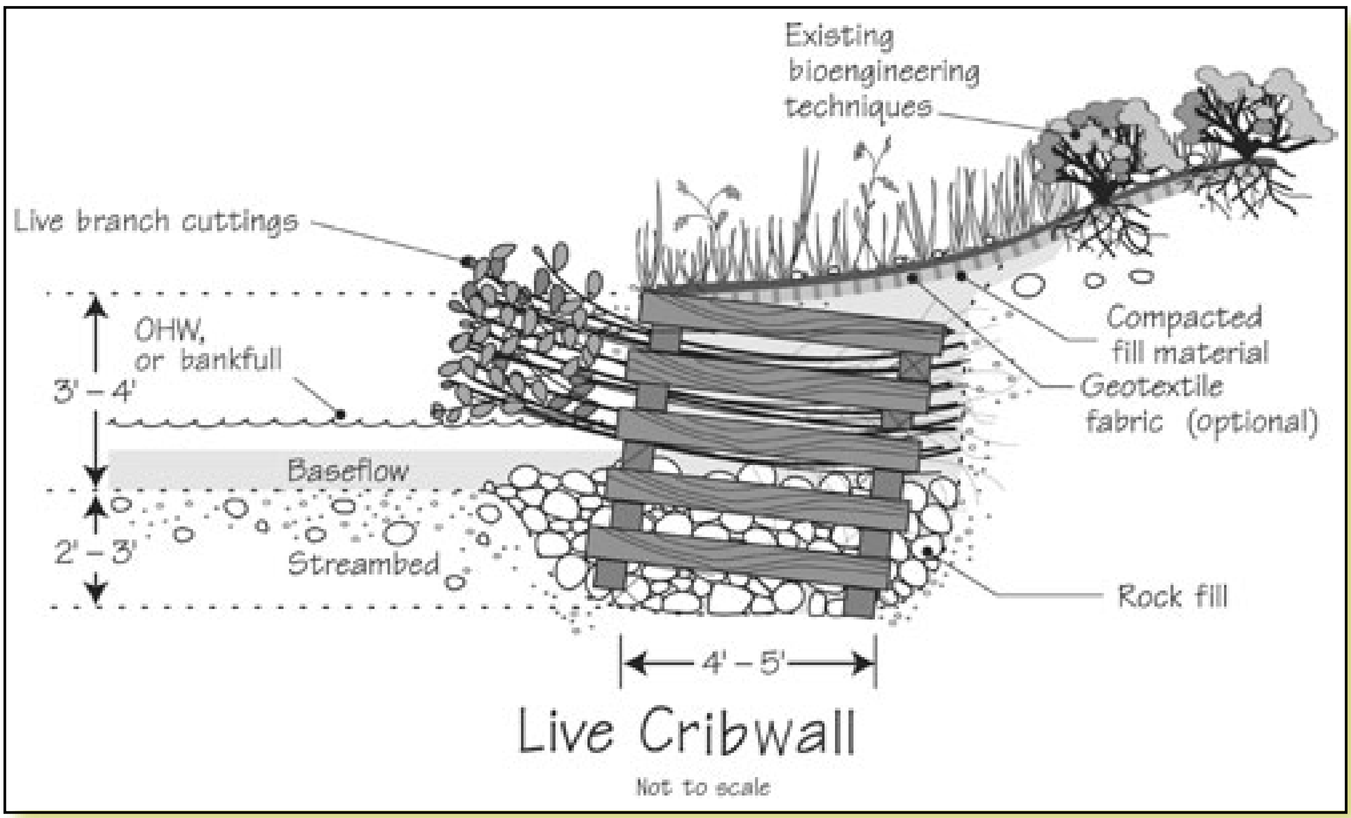


Figure 3–68—Installing live crib walls (Eubanks and Meadows 2002). *OHW* stands for ordinary high water.

- An excellent way of providing habitat.
- A way of providing long-term stability and immediate protection from erosion.

Live Materials for Cribwalls

Live branch cuttings should be from 0.5 to 2.5 inches (13 to 64 millimeters) in diameter and long enough to reach the back of the wooden crib structure.

Inert Materials for Cribwalls

- Logs or untreated timbers should range from 4 to 6 inches (100 to 150 millimeters) in diameter. Lengths will vary with the size of the crib structure.
- Large nails or reinforcement bars are required to tie the logs or timbers together.
- Fill rock should be 6 inches (150 millimeters) in diameter.

Installing Live Cribwalls

- Excavate the base of the streambank from 2 to 3 feet (610 to 910 millimeters) below the existing streambed, creating a stable foundation from 5 to 6 feet (1.5 to 1.8 meters) wide.
- Excavate the back of the stable foundation closest to the slope from 6 to 12 inches (150 to 310 millimeters) lower than the front of the foundation to make the structure more stable.
- Place the first course of logs or timbers at the front and back of the excavated foundation, about 4 to 5 feet (1.2 to 1.5 meters) apart and parallel to the slope.
- Place the next course of logs or timbers at right angles (perpendicular to the slope) on top of the previous course, overhanging the front and back of the previous course by 3 to 6 inches (about 80 to 150 millimeters). Each course of the live cribwall is placed in the same manner and secured to the preceding course with nails or reinforcement bars.
- Place rock fill in the openings in the bottom of the crib structure until it reaches the existing elevation of the streambed. In some cases, rocks need to be placed in front of the structure for added toe support, especially in outside stream meanders. A log revetment may be an alternative to a rock toe.
- Place the first layer of cuttings on top of the rock material at the base-flow water level. Change the rock fill to soil fill at this point. Ensure that the basal ends of some of the cuttings contact undisturbed soil at the back of the cribwall.
- Place live branch cuttings at each course with their buds oriented toward the stream. Place the basal ends of the live branch cuttings so that they reach undisturbed soil at the back of the cribwall with the growing tips protruding slightly past the front of the cribwall. Cover the cuttings with soil and compact the soil. Wet each soil layer.
- Use an engineering analysis to determine the appropriate dimensions. The live cribwall structure, including the section below the streambed, should not be more than 7 feet high (about 2 meters).
- Do not make a single constructed unit any longer than 20 feet (about 6 meters).

Live Fascines or Wattles

A fascine is a long bundle of branch cuttings bound together to form a cylindrical structure. Live fascines (figures 3–69a and 69b) help control surface erosion. Roots from sprouted fascines help stabilize the bank. Fascines should be placed in a shallow contour trench on a dry slope and at an angle on a wet slope to reduce erosion and shallow sliding.

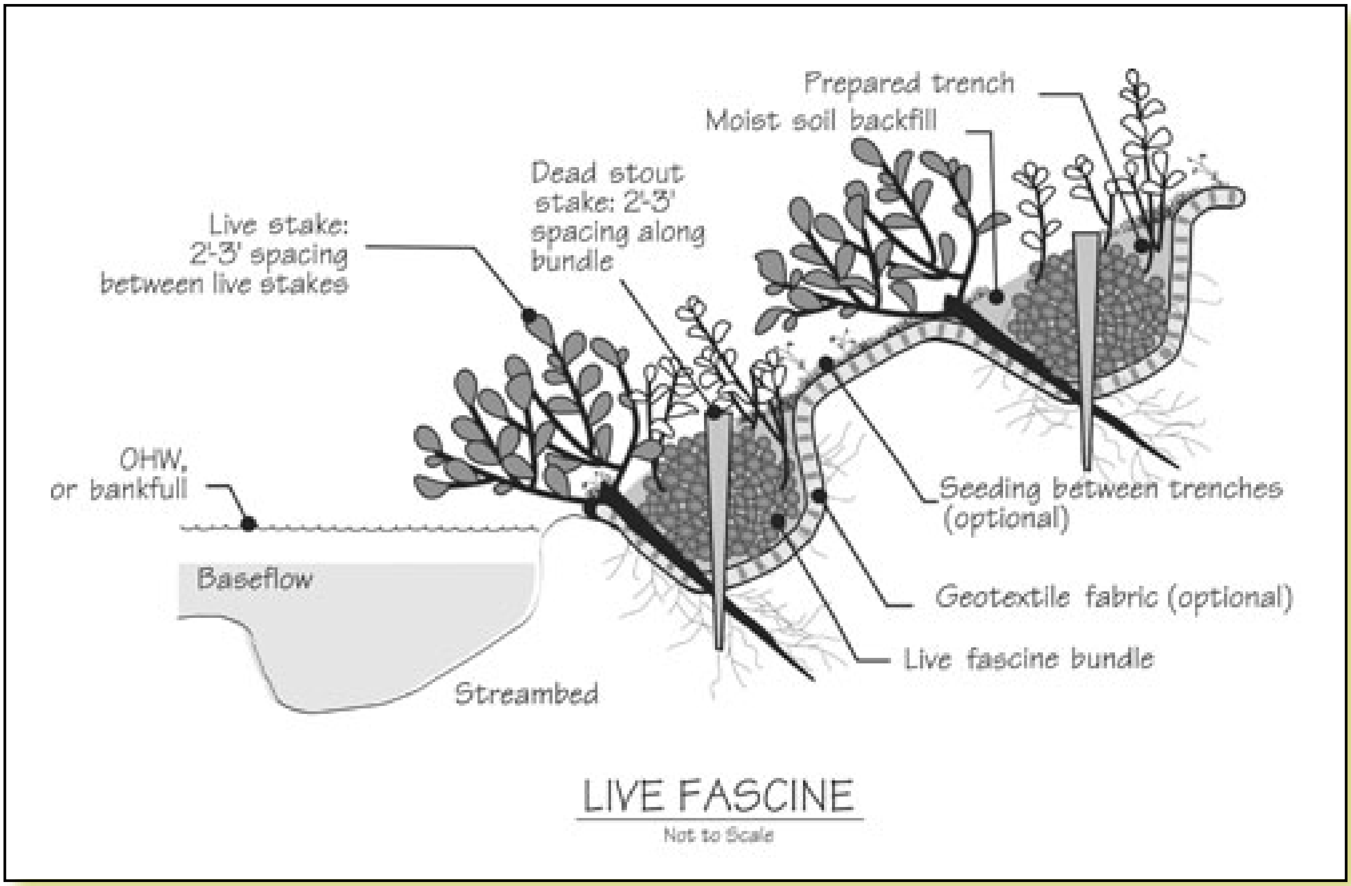


Figure 3–69a—Installing live fascines (Eubanks and Meadows 2002). *OHW* stands for ordinary high water.

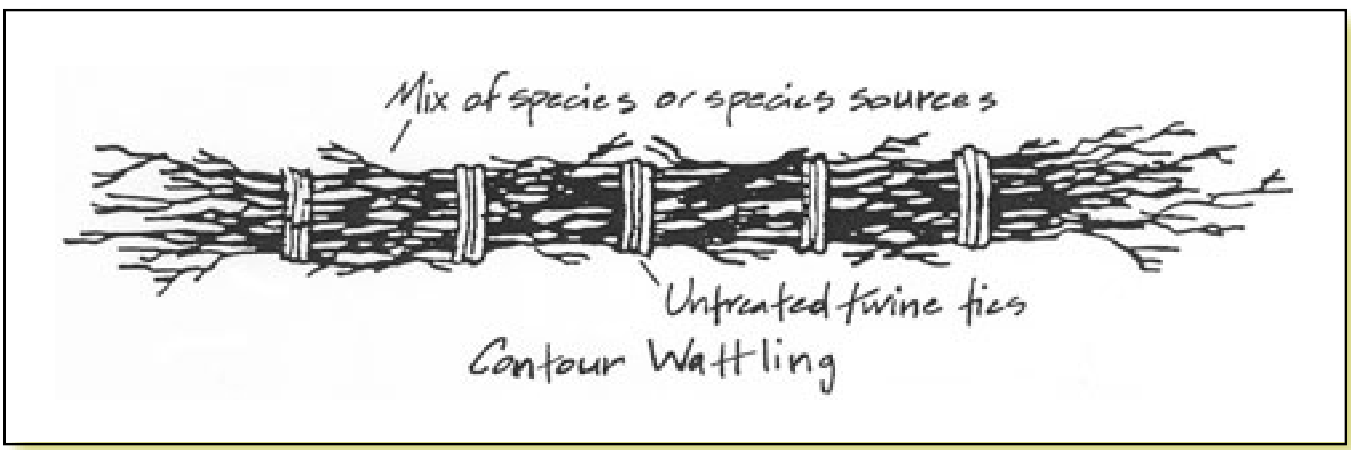


Figure 3–69b—The fascines are long bundles of branch cuttings. Drawing courtesy of Lisa Lewis (Lewis and Ogg 1996).

Applications for Live Fascines

- Install fascines above the ordinary high-water (OHW) mark or the water level when the stream is bankfull, except along small drainage areas (less than 2,000 acres, or about 809 hectares).
- Install fascines between the high- and low-water marks on the bank in arid climates.

Effectiveness of Fascines

Fascines:

- Trap and hold soil on a streambank using small dam-like structures to create a series of short slopes.
- Protect slopes from shallow slides up to 1 or 2 feet (300 to 610 millimeters) deep.
- Require soil moisture or regular precipitation during the growing season.
- Cause minimal site disturbances when properly installed.
- Offer immediate protection from surface erosion.
- Enhance conditions for colonization of native vegetation by stabilizing the surface and creating a microclimate conductive to plant growth.
- Serve to facilitate drainage when installed at an angle.

Live Materials for Live Fascines

Cuttings must be from species (such as young willows or shrub dogwoods) that root easily and have long, straight branches.

- Tie cuttings that are ½ to 1½ inches (13 to 38 millimeters) in diameter together to form live fascine bundles that are 5 to 10 feet (1.5 to 3.1 meters) long or longer, depending on site conditions and handling limitations.
- Stagger the cuttings in the bundle so that the tops are evenly distributed throughout the length of the live fascine. The completed bundles should be 6 to 8 inches (about 150 to 200 millimeters) in diameter.
- Ensure that the live stakes anchoring the fascine are at least 2½ feet (760 millimeters) long.
- Table 3–10 has spacing recommendations for live fascines.

Table 3–10—Spacing for live fascines.

	Soils		
Slope steepness	**Fill** ft (m)	**Erosive** ft (m)	**Nonerosive** ft (m)
Flatter than 3:1	3 to 5 (0.9 to 1.5)	5 to 7 (1.5 to 2.1)	3 to 5 (0.9 to 1.5)
Steeper than 3:1	3* (0.9)	3 to 5 (0.9 to 1.5)	Not recommended

* *Not recommended alone.*

Inert Materials for Live Fascines

- Use untreated twine to tie the fascines.
- Use dead stakes. Make stout, dead stakes from ½- to 4-foot- (0.15- to 1.22-meter-) long, sound, untreated, 2- by 4-inch- (50- by 100-millimeter-) lumber. Cut each board diagonally across the 4-inch (100-millimeter) face to make two stakes. Use only sound lumber. Discard any stakes that shatter when they are installed.

Installing Live Fascines

- Prepare the live fascine bundle and live stakes immediately before installation. If possible, have a fascine-tying team, a digging team, and a fascine-laying team. Team members can do double duty; all members must know their roles ahead of time.
- Jam the ends of fascines together, for longer fascines, before placing them into the trench.

- Begin at the base of the slope, marking contours before digging.
- Excavate a trench on the contour about 10 inches (about 250 millimeters) wide and 10 inches (about 250 millimeters) deep.
- Excavate trenches up the slope at 3- to 5-foot (0.9- to 1.5-meter) intervals. Where possible, place one or two rows of fascines over the top of the slope to break up sheet runoff.

Erosion-Control Blanket Logs

Make your own logs out of erosion-control blankets. These logs can reinforce a streambank without much site disturbance. Each log is 1 to 2 feet (310 to 610 millimeters) in diameter and made out of erosion-control blankets or jute, straw, and lengths of branch cuttings (figure 3–70). The logs are placed along streambanks to armor them. They can be from a few feet long up to 100 feet (31 meters) long.

Figure 3–70—Live fascines rolled into erosion-control blankets can be used as “logs” to stabilize erosion along streambanks (Eubanks and Meadows 2002).

Applications for Erosion-Control Blanket Logs

- Make logs in the field (figure 3–71) to meet needs on the site.
- Apply logs at the ordinary high-water mark or the water level when the stream is bankfull.
- Stack logs to cover more of the bank; on smaller streams a single string of logs may suffice.
- String logs together along the banks, overlapping logs and molding them to the curvature of the streambank.
- Plant logs with rooted stock, sedges, and other plants between the logs and the bank.

Figure 3–71—Erosion-control blanket logs are prepared by rolling out the erosion-control blanket, adding a layer of loose straw, and rolling a live fascine into the blanket.

Effectiveness of Erosion-Control Blanket Logs

Erosion-control blanket logs:

- Armor the toe of the bank effectively while plants take root.
- Protect slopes from shallow slides or from being undermined, while trapping sediment that encourages plant growth within and behind the log.
- Retain moisture in the log, which aids vegetative growth.
- Provide an inexpensive method for stabilizing banks.

Live Materials for Erosion-Control Blanket Logs

- Collect straight branch cuttings, 0.5 to 1 inch (13 to 25 millimeters) in diameter and from 4 to 7 feet (1.2 to 2.1 meters) long, from species that root easily from cuttings (such as willow, dogwood, and cottonwood).
- Use live stakes.

Inert Materials for Erosion-Control Blanket Logs

Inert materials that will be needed to install erosion-control blanket logs include:

- Straw.
- Untreated twine to tie the logs as they are made.
- Cable and duckbill anchors.
- 5⁄16-inch (8-millimeter) cable and cable clips.
- Coconut and jute mat—sold by the square foot in rolls 8 feet (2.4 meters) wide and up to 1,000 feet (304 meters) long. Mesh with openings of 3⁄8 to 1⁄2 inch (10 to 13 millimeters) has been used successfully.

Use stout, dead stakes to secure the log. Make stout, dead stakes from sound, untreated, 2- by 4-inch (50- by 100-millimeter) lumber that is 2 1⁄2 to 4 feet (about 0.8 to 1.2 meters) long. Cut each stake diagonally across the 4-inch (100-millimeter) face to make two stakes. Use only new, sound lumber. Discard any stakes that shatter when they are being installed.

Installing Erosion-Control Blanket Logs

- Cut the mat to the length required for each segment plus 2 feet (610 millimeters). The mat will be 8 feet (2.4 meters) wide.
- Lay the mat flat and cover it with a layer of straw, leaving 1 foot (310 millimeters) of mat at each end of the 8-foot (2.4-meter) edge uncovered.
- Place the cuttings lengthwise along one long edge, three to four stems together.
- Fold the empty edges inward, along the 8-foot (2.4-meter) border, onto the straw.
- Roll up the mat, starting at the edge opposite the cuttings.
- Tie the roll in several places to secure its shape. Use twine or loose coconut strands from the matting as ties.
- Place the log in position on the streambank at the average water level with the cuttings against the bank.
- Start at the downstream end of a section of logs. Place the first log and overlap it with the next one by 1½ feet (460 millimeters). Overlap the logs so that the new log is on the stream side of the original log. One log about 70 to 100 feet (21 to 31 meters) long is stronger than several shorter logs.
- Secure the log with cable spaced every 2 to 2½ feet (610 to 760 millimeters). Wrap the cable around the log and secure the cable by driving a duckbill into the bank. Be sure the anchor is in firm soil.
- Drive live stakes through the log to help anchor it and to add more plant material.
- Use stout, dead stakes, if desired, to anchor the log in placid settings.
- Key in the upstream and downstream ends.

Trench Packs

Trench packs act to break the force of moving water and to trap sediment. They are deciduous branch cuttings placed vertically in trenches or holes (figure 3–72). Plant cuttings should be selected from the same zone in which they will be planted, such as at the stream's edge, on the bank, or on the floodplain.

Applications for Trench Packs

- Install trench packs at the ordinary high-water mark or the level of the water when the stream is bankfull to stabilize the toe of slopes and to provide good fish habitat.
- Use trench packs on lakeshores to reduce erosion caused by wind and waves.
- Use trench packs in gullies to catch sediment.

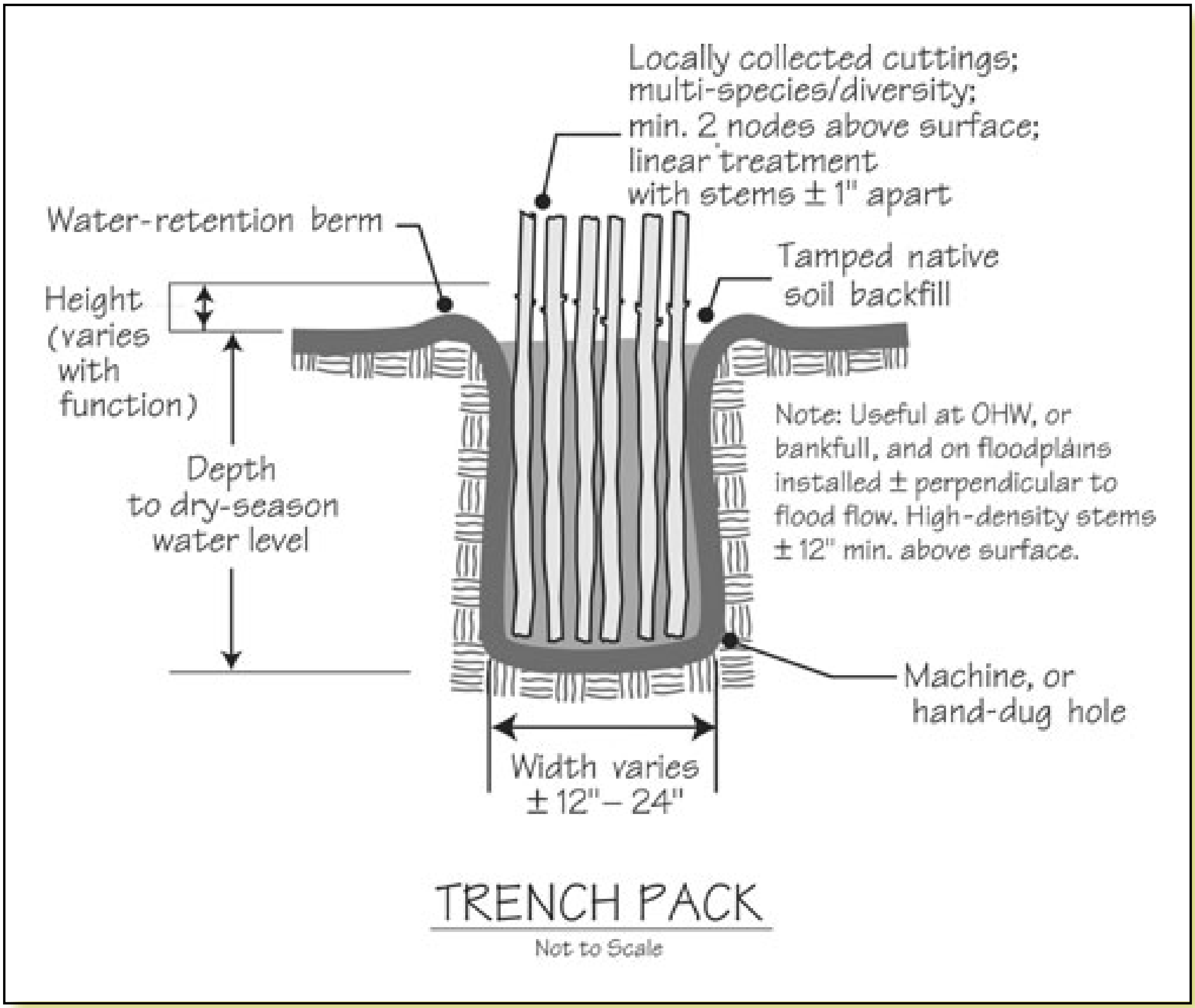


Figure 3–72—Installing trench packs (Eubanks and Meadows 2002). *OHW* stands for ordinary high water.

Effectiveness of Trench Packs

Trench packs:

- Trap sediment.
- Reduce the velocity of wind and water.
- Provide a good barrier for rooted stock.
- Dry excessively wet sites through evapotranspiration (pumping water through the roots to the leaves and into the air).
- Reinforce soil with unrooted branch cuttings. Deep roots help keep the soil from sliding and help keep the bank from sloughing.
- Enhance conditions for colonization of native vegetation by creating a stable surface and a microclimate conducive to plant growth.

Live Materials for Trench Packs

Use live deciduous material about 1 to 1½ inches (25 to 38 millimeters) in diameter, known for its good rooting structure. Leave side branches attached. Mix different species, if appropriate.

Use cuttings that are long enough to reach the water level during the dry season.

For fall planting, branches should extend 2 to 3 feet (610 to 910 millimeters) above the ground to provide immediate bank protection. The following spring, trim the branches back to two buds above the ground, stimulating root growth.

For spring planting, branches should not extend more than 12 inches (305 millimeters) above the ground and branches should not have more than two buds.

Inert Materials for Trench Packs

- Augment the pack with dead material, such as conifer branches, if live plants will not provide enough structural stability before they root.
- Plant branches 3 to 4 feet (0.91 to 1.22 meters) deep if the planting is subjected to moving, erosive water. In other situations, at least one-half the length of the cutting should be in the ground.

Installing Trench Packs

- Dig a hole or trench 12 to 24 inches (305 to 610 millimeters) wide to the water level of the stream or lake during the dry season. Although the trench can be of any length, the ends of the trench must be tied into something solid or keyed into the bank.

Woven Checkdams

Woven checkdams are constructed of woody stem material that will sprout and form a live structure (figure 3–73). The ends of each stem are toed into the channel bottom and banks (Prunuske 1987).

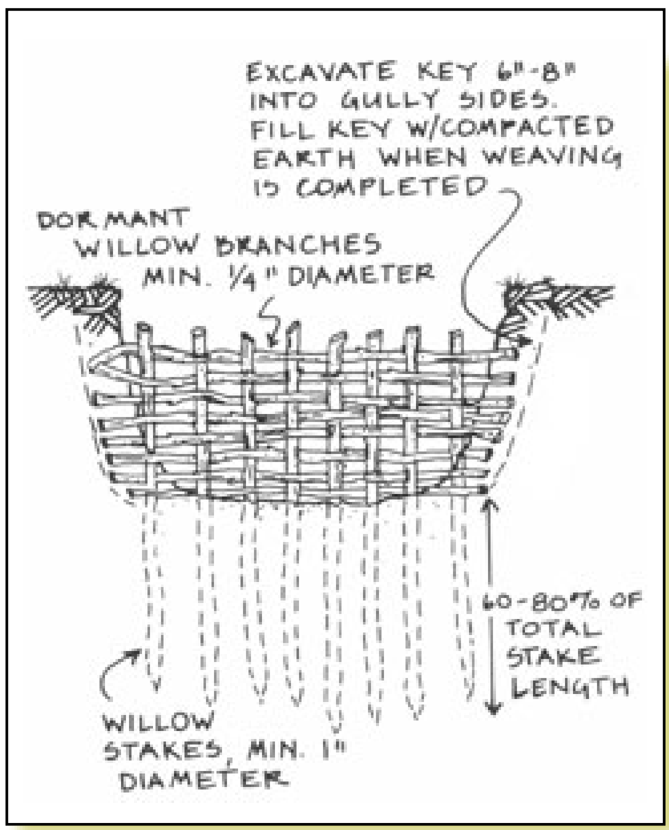


Figure 3–73—Installing woven checkdams. Drawing courtesy of Susan Pinkerton (Prunuske 1987).

Applications for Woven Checkdams

Checkdams:

- Allow water to move through the checkdam.
- Are used for gullies where storm flows have been diverted.
- Are used for gullies where the channel is cut deeper than needed for extreme storm flows.

Effectiveness of Woven Checkdams

Checkdams:

- Trap sediment.
- Slow water and wind.
- Enhance conditions for colonization of native vegetation by creating a stable surface and a microclimate conducive to plant growth.

Live Materials for Woven Checkdams

- Use live, dormant deciduous material known for its good rooting structure.
- Install materials the same day that they are prepared.
- Vertical stakes should be at least 3 inches (76 millimeters) in diameter (larger for a tall dam), and 2½ times longer than the desired height of the checkdam. Use cuttings long enough to reach the water level during the dry season. Cut the basal ends at an angle or point so they can be inserted into the soil easily. The top should be cut square.
- Horizontal cuttings should be at least ¼ inch (6 millimeters) in diameter and 12 inches (305 millimeters) longer than the width of gully being repaired.

Installing Woven Checkdams

- Excavate a key 6 to 8 inches (150 to 200 millimeters) deep into the sides of the gully.
- Strip the vertical stakes of all their side branches.
- Drive vertical stakes into the gully bottom with 60 to 80 percent of each stake anchored underground.
- Weave horizontal cuttings between the vertical stakes, inserting 6 inches (150 millimeters) of the horizontal stakes at either end into the key.
- Fill the key with compacted soil after the stakes have been woven.
- Because water will flow through the dam, structures to dissipate energy are not needed. Add an apron if substantial flow is anticipated.

3.5 Using Soil Binders

Soil binders, also called tackifiers, aggregate the top layer of the soil to reduce dust and prevent surface erosion. The slurry used in soil binders is made from wood products, plaster, petroleum, or other materials. Seed can be mixed into the slurry for hydroseeding. Soil binders commonly are used on raw road cutbanks and fill slopes after construction projects. They are applied with large motorized sprayers. Soil binders typically would not be included in a wilderness or backcountry project, because the projects are smaller and motorized equipment may not be allowed.

Binders are applied after a project's earthwork is complete. Binders sometimes inhibit water infiltration and prevent seeds on the surface from becoming established, because they dry up. In such cases, binders could interfere with restoration goals (Belnap and Furman 1997). The use of soil binders may merit further research as a way of addressing challenging situations.

3.6 Using Icebergs

Site preparation includes installing icebergs where they are appropriate. Icebergs are large natural objects found at your project site, such as rocks or logs, that are buried with about one-third of the mass aboveground and at least two-thirds belowground. Arrange icebergs so they appear to be natural (figure 3–74).

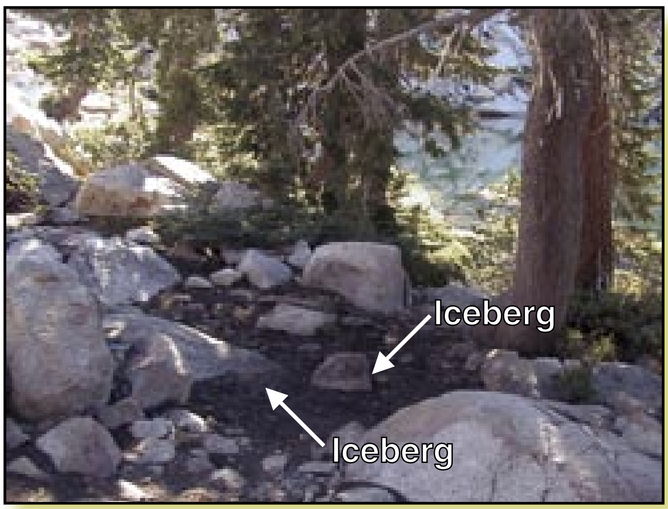


Figure 3–74—Icebergs (deeply buried rocks) are an effective tool for discouraging overnight use of closed campsites. In this example from the Desolation Wilderness, CA, crews artfully selected and placed two rocks that blend well with natural patterns, but make the site undesirable for camping.

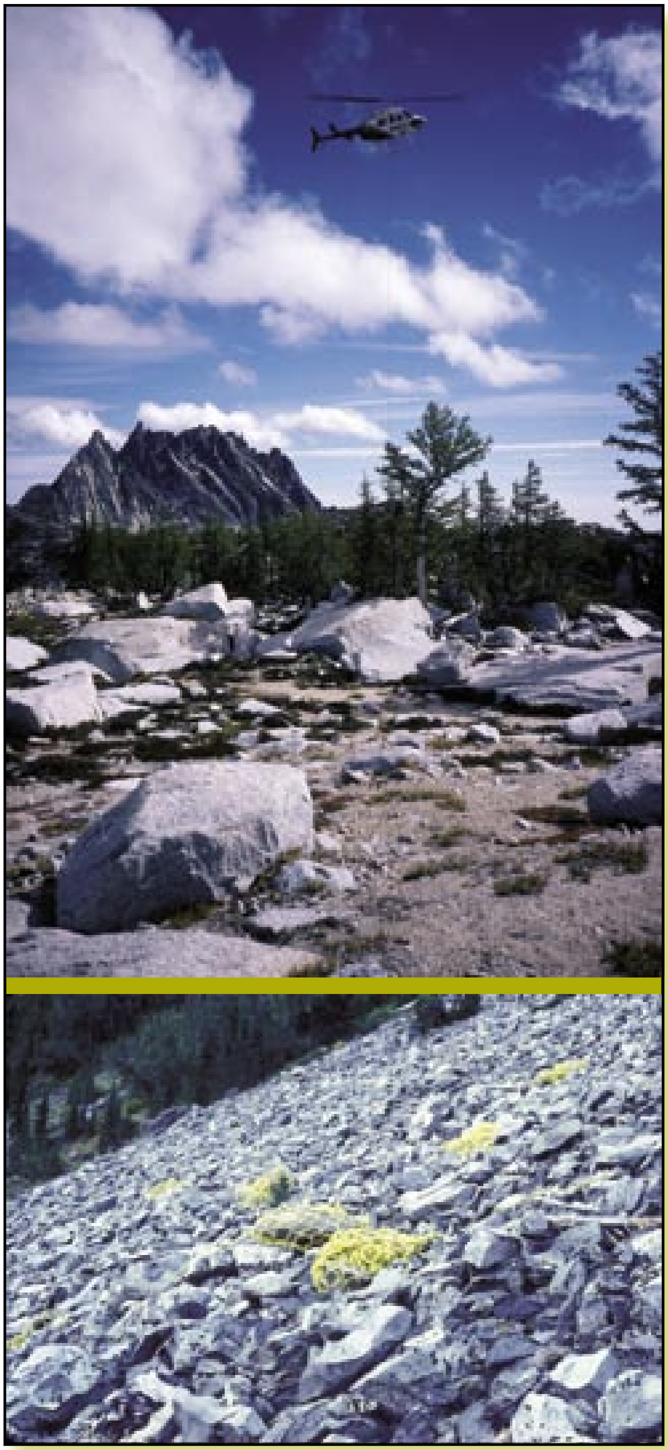
Icebergs are installed for several reasons—to deter users from camping in a restoration site, to shrink a campsite, and to provide microsites where vegetation can become established. Logs (figure 3–75) provide habitat for fauna and fungi. Although it is more difficult to make artificial snags look natural, trees can be buried upright (figure 3–76) to deter use on a site.

It is tempting to install icebergs that have sharp points so visitors won't sit on them. Doing so is counterproductive unless the iceberg blends in with the surrounding rock and is sunk deeply into the ground. Industrious visitors will simply grab hold of the iceberg and yank it out.

Figure 3–75—This punky log looks like it has been at this site in the Desolation Wilderness, CA, forever. My, but that restoration crew is clever!

Figure 3–76—Restoration crews at Olympic National Park, WA, are clever, too— the stump in the center of the photo looks like it grew here, but it was installed to discourage campers from using this site.

Moving large rocks to make icebergs can be a challenge. The U.S. Department of the Interior National Park Service moves rock from nearby talus slopes with helicopters (figures 3–77a and 77b). Primitive methods include using a grip hoist or making litters to support the rock so workers are able to walk in an upright position while sharing the load (figure 3–78).



Figures 3–77a and 77b—At Olympic National Park, WA, helicopters (top) have carried talus to harden campsites or close restoration sites (bottom). The National Park Service sometimes uses helicopters as the minimum tool when managing wilderness.

Figure 3–78—Litters can be improvised to move rock. Grip hoists can be used to drag larger rocks, but doing so would damage vegetation.

Icebergs also can be used to attract use. In places you want people to use, a large rock with a flat surface is like a piece of furniture (figure 3–79). Lest providing such furniture offends your wilderness sensibilities, consider this: the rock provides a hardened place for people to sit, set up their camp kitchen, or lean their packs. If the rock is within a hardened site, this tactic helps concentrate impacts in the impacted area. Otherwise, campers are drawn to other nearby rocks or trees that will serve the same function, widening the zone of impacts.

Figure 3–79—Rock added as “Flintstone furniture” helps confine use within the impacted perimeter of designated campsites. Flat rocks can serve as a kitchen, a place to sit, or a place to lean backpacks.

3.7 Site Delineation

Visitors to public lands often are oblivious to the ease with which vegetation can be damaged. Visitors may walk, sit, camp, and tie up their animals on fragile, vegetated areas. Visitors can and will take the shortest or most interesting route possible, even when it means leaving hardened surfaces that could resist trampling. An important method for subtly—or not so subtly—channeling use is site delineation (Scott 1998). Barriers are installed during site preparation because installation requires disturbing the area.

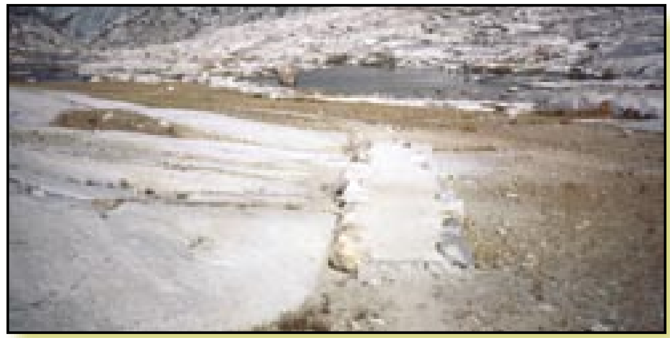


Figure 3–81—Rows of rock keep users on the Pacific Crest Trail in the John Muir Wilderness, Sequoia-Kings Canyon National Park, CA.

3.7.1 Barriers

You can delineate where you would like to keep users out (an exclosure). For instance, the rail fence in figure 3–80 is intended to keep visitors from using a restoration site. Or you can delineate where you would like to keep visitors in (an enclosure), such as when you define the edges of a campsite or trail (figure 3–81).

The size of the barrier and the materials it is made from are intended to match the awareness level of users. Remember minimum requirement principles, because barriers may not always seem like a light-handed technique in wilderness. In locations with informed users, plantings may be the barriers—tree seedlings could block a path, for instance. Low-profile barriers, such as a row of rocks that lines trails or small-diameter logs (figures 3–82a and 82b) pegged into

Figure 3–80—Barriers can help keep visitors from using a restoration site. This rail fence is near a road pullout at Natural Bridges National Monument, UT.

Figure 3–82a and 82b—These low-profile log barriers (top) delineate a trail through a closed restoration site. The barriers also serve as silt dams for backfilling the restoration sites. Log carriers (bottom) placed underneath the log are useful when transporting log barriers.

place along a trail, are slightly more obtrusive, but will keep visitors out of your restoration sites in some areas. With enough attention, these barriers can be designed so they are not obtrusive (figure 3–83).

Figure 3–83—The rocks and log used to block this social trail in the Desolation Wilderness, CA, blend in so well that the average user may not notice them.

You may determine that hefty fence-like barriers are needed for your visitors. Ruth Scott, a veteran restoration practitioner at Olympic National Park, has learned through experience that large logs or rocks often are needed to corral users.

3.7.2 String Fences

String fences are commonly used to delineate restoration sites. String fences are inexpensive, easy to transport, and easy to install. Their height can be adjusted easily by changing the length of the stakes. Unfortunately, string fences are a high-maintenance item, easily collapsed by snow or unknown dark forces. In addition, string fences have a less natural appearance than native materials. String fences are certainly not a long-term solution for site management. However, they are a good short-term fix to funnel use in areas where the vegetation will soon take over or when other options are not practical.

A Restorationist's Tale

One weekend day, while on patrol at Snow Lake in the Alpine Lakes Wilderness, I stepped within earshot of one of our recently closed and treated restoration sites. The site was covered with jute matting (figure 3–84) that had plugs of native vegetation poking through. A string fence, installed to block the site from use, had fallen into disrepair. Two people had plunked themselves down in the middle of the site to enjoy their picnic lunch. Just as I felt my ire rising and I was searching for words of diplomacy, I heard the woman in the group say, in a loud shrill voice, "Isn't it nice that they put down a mat so that we have a nice clean place to sit?"

—Lisa Therrell

Figure 3–84—The scene of the crime. String fences can discourage visitors from using restoration matting as a seat cushion.

If you use a string fence, (figures 3–85a, 85b, and 85c), it is best to construct it from parachute cord or heavier cord. Stakes need to be made from 1- by 2-inch (25- by 51-millimeter) lath or bigger material to withstand snow and marauders. Small Lexan or Rite-in-the-Rain paper "Restoration Site" signs are available that can be attached to the cord with wire (see chapter 5, *Tools of the Trade and Other Resources*, for a source of signs).

Figure 3–85a—While string fences can rope off large expanses or block a trail, they require perpetual maintenance.

Figure 3–85b—Small Lexan or Rite-in-the-Rain paper "Restoration Site" signs are available that can be attached to the cord with wire.

Figure 3–85c—Specially marked stakes are more durable.

3.8 Blending Restoration Projects Into Wilderness

Some readers may be mortified after reading a discussion of recontouring sites and installing barriers and Flintstone furniture. These techniques seem quite manipulative and too structured for many wilderness settings. The challenge is to determine when these techniques really are the minimum tool, then designing the project so it blends with local landscape features as much as possible.

3.9 Common Wilderness Campsite and Trail Problems

Parallel Trails

When parallel trails are not deeply eroded, the unneeded trails usually can be obliterated by using plantings, rocks, and logs to deter continued use (figure 3–86). The "real" trail is left open and improved to correct any problems that may have led to the formation of parallel trails. Usually, the problem was that the trail was muddy when wet or was too rough or narrow to invite continued use.

Figure 3–86—If a parallel trail is not deeply eroded, it can be blocked with rocks or logs and planted to repair the damage. This trail is in the Eagle Cap Wilderness, OR.

With a large enough budget, restorationists could install lots of checkdams and backfill parallel trails with imported fill, returning them to the original slope contour.

Many Forest Service projects don't have the funding to allow such approaches, and the agency is less likely to use a helicopter to support a wilderness restoration project. A compromise solution is to create a broad swale by digging up and rearranging the raised ridges of vegetation separating each parallel trail.

Digging up and moving surviving vegetation is not completely desirable. Do so only if the result seems more desirable than leaving the visual lines and erosion channels of the parallel trail trenches.

Human use might be directed onto a relocated trail, which contours the slope at a sustainable grade. Alternatively, rock or log steps that serve as siltdams could be installed to allow the trail to be improved at its original location (figures 3–87a and 87b). If your trail is used by stock or bicyclists,

Figures 3–87a and 3–87b—Several steep, parallel trails (top) plunged down an embankment at Snow Lake in the Alpine Lakes Wilderness, WA. One trail was hardened by installing rock steps. Other trails (bottom) were closed and restored.

make sure that each step is longer than the length of a horse or bicycle, and short enough that a chain sprocket will not hang up.

Deeply Eroded Trails

Deeply eroded trails are difficult to erase without adequate fill and substantial labor. The permanent scar of the old trail—often partially filled with rock or wood chunks to slow the movement of water and trap silt—is evidence of many trail relocation projects.

Ideally, checkdams will be installed in the old trail and backfilled at ground level. If surface erosion is being directed toward the trail, it may be possible to trap additional sediment behind checkdams.

In forested or brushy areas, a compromise solution would be to stabilize the trail with lower angle checkdams and backfill, then to design the vegetative treatment to include some taller plants that will break up the visual effect of the trench. If the trail includes large step-downs caused by headcutting, the slope angle will need to be laid back. If the project location supports riparian vegetation, a bioengineering treatment—such as the trench pack—might help. If the trail cannot be treated successfully, give serious consideration to hardening the trail.

Trails That Contour

Sometimes a trail that contours is slated for restoration. If the trail has had little or no erosion, pull the berm or fill at the outer edge of the trail back into the tread as much as possible. If the trail is more deeply eroded, determine whether it is more effective to pull the berm in—exposing a large raw area but reestablishing the contour—or to use a series of checkdams and backfill. If the tread remains incised, be sure to include drain dips or waterbars as you would for a system trail. Controlling ongoing erosion by directing water off the trail will be important to the project's success.

Excavated Campsites

Some campsites have an excavated cutbank where the site was carved into the hillside. If the fill is still available on the downhill edge of the site, it can be moved back into the cut. Logs or rock can be arranged to stabilize the new contour. Without treatment, many sites will continue to erode back into the slope because of rodent activity or wind action.

Eroded Campsites

A site on a slope might continue to erode from water, wind, human use, or even animal activity. Checkdams or siltbars can be installed to stabilize the slope in shallow benches and fan out running water (figure 3–88) to slow it down. Be sure to evaluate whether the water should be directed away from the uphill side of the site. For example, a well-placed drain on the trail accessing the site may prevent water from coursing through the site. This same approach can be used to stabilize a campsite you wish to keep open for use, leaving large enough flat areas to serve as tent pads. As with an excavated campsite, if erosion is continuing to eat back into a slope, design a way to stabilize the erosion, such as laying rock or organic debris against the eroding cut.

Figure 3–88—Rocks and logs used as low-angle siltbars stabilize the tent space on this campsite at Lake Mary in the Alpine Lakes Wilderness, WA.

3.10 Plant Selection, Collection, and Propagation Techniques

This portion of the guide lays out the factors to consider when you are selecting the plant species to treat restoration sites, the manner in which you collect the plant material, and the propagation methods you might employ. The botanist or plant ecologist (figures 3–89a and 89b) on your team will help you through this process. This guide focuses on the

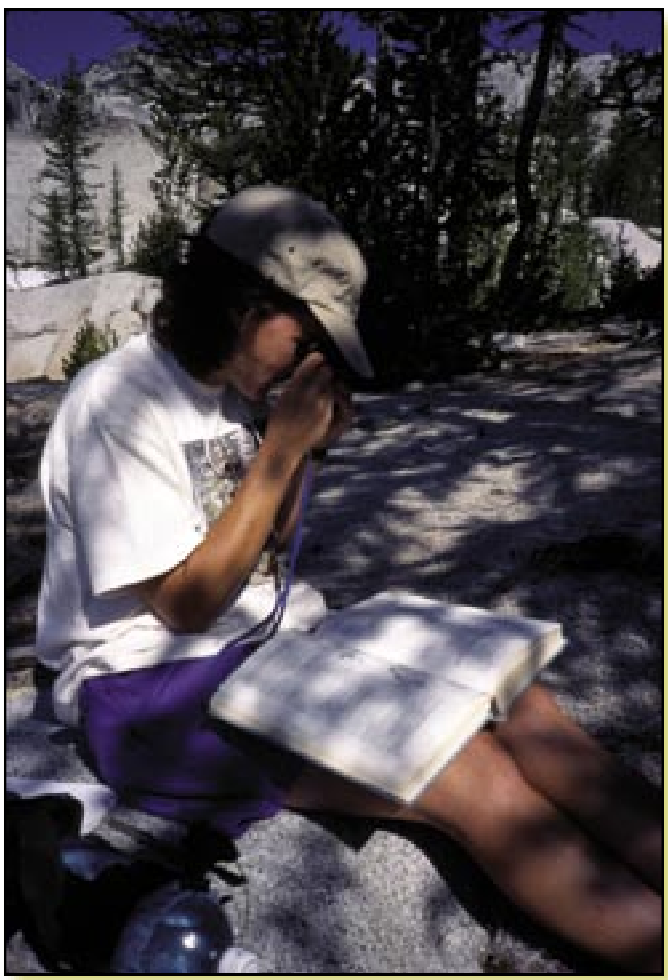


Figure 3–89a—You will appreciate the help of the botanist or plant ecologist on your team when you need to identify and select appropriate plant species for a restoration treatment.

Carex nigricans

Figure 3–89b—"Dang, these sedge flowers have small plant parts!" Drawings courtesy of the University of Washington Press (Hitchcock and Cronquist 1976).

information needed to do work successfully onsite, as well as the knowledge needed to coordinate with a professional nursery. Appendix B, *Propagation and Establishment Requirements for Selected Plant Species*, summarizes additional species-specific information.

3.10.1 Genetic Considerations for Restoration Projects

The design of a restoration project should consider the genetic implications of selecting, moving, and propagating plant materials. Plant movement guidelines define the area over which plant materials, such as seed or cuttings, can be collected relative to the project location to assure restoration success and maintain the genetic integrity of the local plant population. In addition, plant propagation techniques can result in an unintentional selection against a portion of the total genetic material (certain genotypes) represented in the plant material collected for propagation. This section explains these concepts and offers suggestions for minimizing changes to the genetic structure of the area being restored.

Selecting plant material appropriately increases the probability that the plants will survive, grow to maturity, and reproduce with new individuals suited to the local environment. Increasingly, even projects in highly modified environments, such as highway corridors, are using locally adapted native plants (Smith 1994).

Most plants are precisely adapted to their immediate environment. Many species that are widespread are grouped into ecotypes, each of which is adapted to a specifically defined ecological situation within one or more subareas of the species' range. Subpopulations are usually continuous, but maintain their integrity through ecologically specified selection pressures, despite gene flow from the other neighboring "ecological" races (Potash and Aubry 1997). For example, western shrub species (figure 3–90) show strong ecotypic variation in morphology, growth rate, flowering times, cold hardiness, germination patterns, and so on (Meyer and Monsen 1992).

Figure 3–90—Rabbitbrush (*Chrysothamnus* spp.) in Mesa Verde National Park, CO.

Nonlocal stock, especially of native species, can introduce different maladapted genotypes (the total genetic information contained in the plant) into the gene pool of the local plant population. Changes can occur in a number of traits, including plant size and shape, growth rate, seed production, and survival. These changes could be temporary or permanent. Too little is known about possible changes in most plant species to predict the outcome. The degree to which these changes occur depends on the difference between any two subareas, such as alpine, subalpine, or lower elevation environments (Guinon 1992; Potash and Aubry 1997).

In wilderness or other remote sites, there is also an ethical imperative to maintain the genetic integrity of the local plant community. The goal for restorationists should be to use locally adapted plant materials that will not change the genetic composition of the plant community.

Maintaining genetic integrity is an important planning challenge, because specific scientific parameters that could be used to define a seed collection zone are not known for most plant species. Conifer species are an exception. The Forest Service has been refining a seed zone concept for conifers since the 1950s. Professional opinions range widely regarding just how far other species of plants should be moved. For example, some projects have moved plants over hundreds of miles based on ecotype (Redente 1993; Smith

1994). Other projects collected plant materials from within a few feet of the actual site to be treated.

Some agencies have incorporated plant movement guidelines into policy or procedures. Using these policies and working with a geneticist is an important starting point in deciding species-specific plant movement guidelines. In wilderness or other relatively natural settings, err toward preventing unwanted genetic movement, rather than going farther afield to collect plant materials.

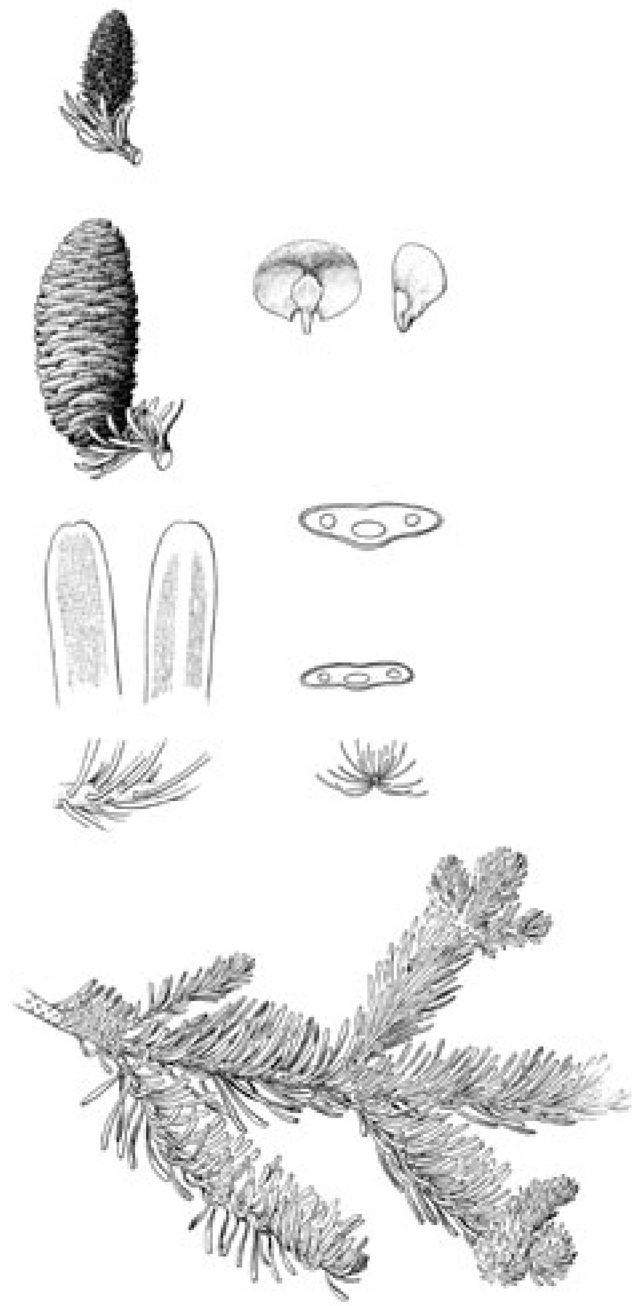
3.10.1a Determining a Local Collection Area

Lacking better information, a local collection area is defined as the combined distance that pollen would be likely to travel plus the distance that seeds would be dispersed. The following considerations will help determine the radius of genetic isolation (Albright 1994; Millar 1992).

The life history of a plant affects genetic diversity. Plants that are wind-pollinated, such as conifers (figure 3–91), alders, cottonwoods, and graminoids (grasses, rushes, and sedges) cross-pollinate over much wider geographic areas than plants that are cross-pollinated by insects. For example, corn pollen generally travels up to a quarter mile (0.4 kilometer), and can travel much farther, depending on wind patterns. Materials from wind-pollinated species can be collected from a larger area without affecting genetic diversity. This is not the case for materials of plants that self-pollinate or that reproduce vegetatively.

The seed-dispersal mechanism, which is generally easy to identify, also has significant bearing on genetic movement. Seed that becomes airborne or that is dispersed by animals (figure 3–92) is likely to travel farther than seed that falls to the ground below the plant or that is transported short distances by ants or rodents. For example, the seed of willows, aspen, poplar, and fireweed can be dispersed for at least 1 mile (1.6 kilometers) by the wind. The heavier seed of paper birch, alder, and spruce can be dispersed up to a quarter mile (0.4 kilometer, Densmore and Vander Meer 1998).

In some cases, changes in a plant's morphology (physical appearance) based on its location can be observed readily. While it is important to collect materials from a variety of



Abies lasiocarpa

Figure 3–91—The windblown pollen of conifers such as subalpine fir (*Abies lasiocarpa*, above) distributes genetic material far from the parent plant. Drawings courtesy of the University of Washington Press (Hitchcock and Cronquist 1976).

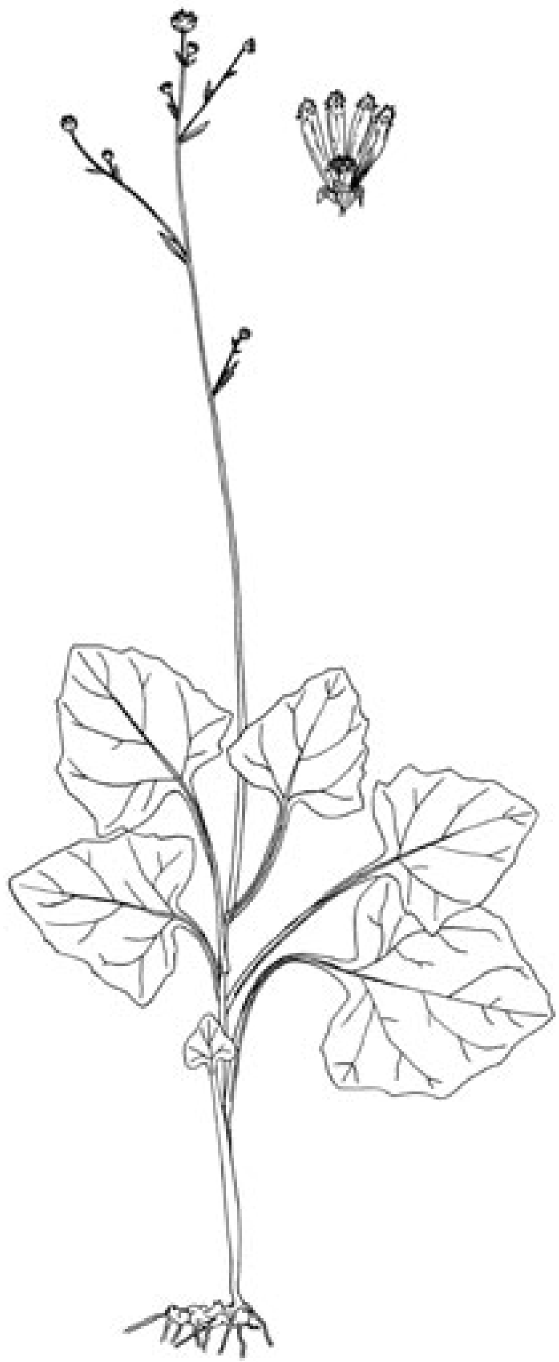


Figure 3–92—The hooked and sticky seed pods of trail plant (*Adenocaulon bicolor*) travel long distances while stuck to the fur of mammals, distributing genetic material farther than the seed of species that may be blown a short distance or that fall to the ground near the plant. Drawings courtesy of the University of Washington Press (Hitchcock and Cronquist 1976).

individuals, if morphological changes are based on identifiable ecological or geographic differences, plants morphologically unlike those at the restoration site should be considered genetically separate and should not be collected.

Ecological barriers may restrict genetic movement. Identify localized breaks in geology, topography, climate, vegetation type, or other ecological extremes. For example, genetic information is more likely to remain in a basin (figure 3–93) than to migrate across ridges. Limit plant collection to an area with the same environmental characteristics as the project area. The more diverse the local habitat of a plant, the greater the local genetic variation (Linhart 1995).

Figure 3–93—Seed or pollen is more likely to remain within a basin than to cross ridges.

3.10.1b Preventing Unintentional Selection

Even if collection distances are carefully determined and followed, the genetic structure of plants can be changed when they are collected for propagation. For instance, too few plants could be collected to assure some genetic diversity, or the plants that were collected could be too closely related. In such situations, propagated plants would run the risk of inbreeding depression and subsequent population decline (Guinon 1992).

Plant materials should be gathered from throughout the collection area. The collector should be familiar with the pollination method of each species, in order to surmise how far to go to gather individuals likely to be unrelated. Small annuals may be unrelated if they are 5 to 11 yards (4.6 to 10 meters) from each other. Forest trees may need to be 110 to 220 yards (101 to 201 meters) away to be unrelated (Linhart 1995). If seed or cuttings are collected from a variety of individuals, a minimum of 30 to 50 parent plants are needed to help preserve all the genetic options available to the population in the project area. If mortality is anticipated at any stage of the propagation process, collect from more donor plants (Potash and Aubry 1997). An equal amount of seed (figure 3–94) or cuttings should be gathered from each plant; overcollecting from heavy seed producers can cause a genetic shift (Meyer and Monsen 1992).

Figure 3–94—When collecting seed and other plant materials, consider how far genetic material would be likely to travel naturally, and emulate that pattern. Here, seed is being collected in the Alpine Lakes Wilderness, WA.

Collect from every microhabitat represented at the project site. Donor plants should not be selected for uniformity or other characteristics such as heartiness; rather, collections should be from individuals that exhibit an array of size, growth form, vigor, and so forth. A trait that may appear to be undesirable could ultimately be the trait that enables a plant to survive in a slightly altered environment. If too few plants are available in the collection area, collections should be made at other sites by matching donor and project site characteristics as closely as possible (Guinon 1992).

The type of plant material collected also will affect the genetic outcome. Seed, which is the product of cross-pollination, is much more diverse genetically than cuttings or plant tissue. Genetic integrity also is maintained by collecting from the wild local population, rather than from offspring grown in a nursery or produced through seed-increase programs that may cause a genetic shift (Meyer and Monsen 1992).

Timing of collection also can be a factor in maintaining genetic variation. Ripening times of seed can vary on the same plant, with each seed lot having different characteristics. When this is the case, seed should be collected at several different times (Meyer and Monsen 1992).

Seed handling and germination procedures affect survival rates, selecting for and against certain traits. Avoid overcleaning seed, which removes smaller seed that may differ genetically from seed of average size. Ensure that seed is cured and stored properly (more on this in the section on handling seed). The best insurance against unintentional selection is to use presowing treatments that break dormancy completely in every viable seed and then to assure the survival of the delicate seedlings. When thinning, do not routinely remove the smaller plants; leave plants with a variety of sizes and other traits (Meyer and Monsen 1992). Ideally, every plant should be saved and used.

Finally, it is important to document where plant materials were collected. This will be considered later when evaluating monitoring results. An example of a collection documentation sheet is included in appendix E, *Forms.*

Native Plant Collection Guidelines for the Mt. Baker-Snoqualmie National Forest

The following example is the summary of a policy developed by a geneticist for a national forest in western Washington based on local ecosystems (Potash and Aubry 1997). This policy is a good illustration of applying the principles described in this section.

Summary of *Guidelines for Native Plant Collection to Ensure Genetic Diversity and Adaptation to Planting Environment*

- Collect from 30 to 50 unrelated plants.
- Collect an equal number of seeds or cuttings from each plant.
- For upland tree species, collect seed and cuttings within (predetermined) seed zones and 500-foot (152-meter) bands of elevation or not more than 250 feet (76 meters) above and below the project site.
- For shrubs, forbs, grasses, and riparian tree species, collect seeds and cuttings within watersheds and 500-foot (152-meter) bands of elevation or not more than 250 feet (76 meters) above and below the project site.

In practice, wilderness restoration practitioners exercise caution in limiting the distances they go to collect plant material. Mount Rainier National Park collects most of its plant material within 200 feet (61 meters) of the project site (Rochefort 2002). The Wenatchee River Ranger District of the Wenatchee National Forest collects from within the same lake basin, up to half a mile (0.8 kilometer) away at the most and no more than 200 feet (61 meters) in elevation above or below the site to be treated. Care is taken to collect from throughout the basin to avoid limiting the gene pool too much and to avoid overharvesting individual stands of plants. Successive collections are taken when possible, and each plant material batch is combined with others of the same species to avoid any genetic bias when propagating or planting.

3.10.1c Additional Information on Genetic Considerations

For more information on genetic considerations for restoration projects, refer to the *Mt. Baker-Snoqualmie National Forest Native Plant Notebook* (Potash and Aubry 1997), *Genetic Considerations* (Meyer and Monsen 1992), and *Promoting Gene Conservation Through Seed and Plant Procurement* (Guinon 1992).

3.10.1d Nonnative Plants, Agronomic Varieties, or Native Cultivars

Thinking about the use of nonnative plants or agronomic varieties for restoration projects has been evolving. Agronomic varieties and native cultivars have been developed from native plants selected for certain desirable traits, such as forage value, drought hardiness, tolerance of alkalinity, or increased seed production. Some grass species have had many agronomic varieties developed from a single species, with each variety specially suited to a specific environment. Agronomic varieties, as the name suggests, are literally farmed, grown in commercial fields to provide a relatively abundant, inexpensive source of seed. These varieties, as well as nonnative plant species, have been used extensively at a landscape scale for many decades, usually to reclaim mines or overgrazed range, or to stabilize slopes after wildland fires (Aubry and others 2005; Monsen 1975; Owen, no date).

The decision to use nonnative plants, agronomic varieties, native cultivars, or even nonlocal native stock usually is based on economy, because these plants are available readily at a lower cost per unit—usually per pound (half a kilogram) of pure live seed per container—than the cost of propagating local native stock. Some have argued that the lower cost of nonnative plants is false economy because the purchase cost does not include the cost to the ecosystems involved (Dalpiaz 1994; Kratz and others 1994; Owen, no date). A number of the most aggressive pest plants in North America were introduced to reclaim erosion or improve forage, including kudzu, purple loosestrife, reed canarygrass (figure 3–95), African lovegrass, tamarisk, and Scotchbroom.

Figure 3–95—Reed canarygrass (*Phalaris arundinacea*) is a native plant in North America. It has been bred as an agronomic variety and used extensively for pasture improvement and streambank stabilization. Because it has underground tillers, reed canarygrass can spread quickly and become invasive, displacing local native plant communities.

To quote a briefing paper from the Rocky Mountain Region of the USDA Forest Service, "We do not know the impacts of exotic plants on animals, insects, and the soil microflora and microfauna" (Kratz and others 1994). According to Berger (1993), the introduction of nonindigenous species may disrupt native ecosystems either through effects on competition or predation, through the introduction of disease vectors, or by affecting mutualistic relationships, such as when insect and plant invaders drastically alter community structure by displacing native plants. The growing body of literature on this topic suggests the following conclusions:

1. Selecting nonlocal native plant material or nonlocal native cultivars is potentially the most destructive course of action because cross pollination and outcrossing are likely to occur, "polluting" the gene pool of the local native plant community (Kratz and others 1994). Selecting nonnatives that are closely related to local natives also is a poor choice because of the possibility of hybridization.
2. Nonnative species, especially agronomic varieties, often will be vigorous for several years before declining in numbers (Brown and Johnston 1979). A number of studies have shown that the introduced species will prevent the initial establishment of native plants (Amaranthus and others 1993; Schoennagel 1997). In addition, some introduced species, depending on growing conditions, are persistent and can outcompete native plant communities. For example, red fescue (*Festuca rubra*) was selected for use at Mt. Rainier National Park based on the prediction that it would not be persistent and would allow natives to invade. The fescue was used extensively for erosion control before it was discovered that it was reproducing both vegetatively and from seed and was too invasive to allow natural succession (Hingston 1982).
3. For projects where nonlocal natives are not available in sufficient quantity and some other plant material must be selected, a sterile, nonpersistent, and noninvasive species would be the best choice (Keigley 1988; Kratz and others 1994). In this approach, the introduced species often is used as a cover crop to improve soil conditions, allowing natives to invade. Restoration research scientist Jayne Belnap advocates the use of a cover crop to maintain soil microbial populations on a disturbed site when

planting with native stock needs to be delayed. Sterile hybrids can help stabilize slopes, especially when natives may be slow to establish extensive root systems (Belnap and Furman 1997). This approach will force the planner to do some careful consulting with geneticists, plant ecologists, or other restoration practitioners to determine the species and seeding rates that might meet these criteria for the project location.

The use of annual ryegrass (*Lomium multiflorum*) as a cover crop to implement approach number 3 has worked in some cases and failed in others. In Rocky Mountain National Park, annual rye was used successfully as a nonpersistent, noninvasive cover crop that allowed future transplants of containerized natives onto the disturbed site. The annual rye also improved soil moisture retention, available nitrogen, and slope stability (Keigley 1988). However, when annual rye was seeded after a wildland fire in a sugar pine (*Pinus lambertiana*) forest type in southern Oregon, the native species cover and richness were reduced, with possible long-term negative effects on slope stability, productivity, and reestablishment of conifer seedlings (Amaranthus and others 1993).

For small projects, such as those addressed by this guide, it would be uncommon to consider using anything other than nonlocal native plants. Larger projects have the potential for even greater ecosystem disturbance when they resort to using nonnative plant materials. The alternative, which involves planning ahead, is to develop adequate sources of appropriate native plant material over time. For large-scale projects, this would start with defining ecotypes for species of interest, and starting large-scale propagation programs such as a seed-increase program to develop an adequate supply of seed for project needs.

Decisions on using nonnative or nonlocal native plant stocks depend on the project's goals. If the goal is to allow for the eventual establishment of a native plant community that approximates the vegetative mosaic before disturbance, local native plant stock should be used. If the goal is merely to revegetate an area for other human benefits, it may be appropriate to consider using nonnative plants. In designated wilderness, where land managers are legally mandated to manage for "untrammeled" landscapes, the latter approach conflicts with the philosophy of the Wilderness Act of 1964, and in some cases, runs counter to agency policy.

3.10.2 Plant Selection for Restoration Projects

The process of selecting plants for a restoration project is essentially a ecological and horticultural feasibility study that begins by selecting a reference site, as described at the start of this chapter. Often, the plant community that is desired to meet long-term goals for the area is not within immediate reach because of any number of limiting factors, including environmental conditions, the degree of disturbance at the site, continuing patterns of destructive use, difficulties in propagation, and budgetary constraints.

The very first consideration is whether natural revegetation might be possible as the minimum tool. This concept was described more fully in chapter 2. Natural revegetation may be possible, for example, if the soil has a known seedbank, if other live plant material could revegetate the site, or if the environment is lush and recovers quickly. Sometimes plants are not the dominant feature of the landscape. The appearance of restoration can be accomplished by other means, such as recontouring and replacing missing features (rock, for instance). Vegetation can be allowed to recover naturally. This approach can be successful in environments such as deserts or alpine fellfields (rocky habitats with a cover of low plants on exposed alpine summits and ridges).

Wilderness Restoration and the Colorado Fourteeners

The Leadville Ranger District of the San Isabel National Forest developed an interesting partnership for managing scrambling routes on the Colorado Fourteeners (peaks higher than 14,000 feet [4.27 kilometers]). Despite being in a "trailless" zone, many of these peaks were scored by steep, eroding parallel trails. Volunteers organized by the Colorado Fourteeners Initiative (*http://www.14ers.org*), are establishing one stable trail to each peak. The remaining routes are being obliterated and allowed to revegetate naturally (figure 3–96). Wilderness rangers have observed limited establishment of native seedlings on some of these routes after use has been eliminated.

Figure 3–96—Mount Belford (elevation 14,197 feet, 4,327 meters) is one of more than 50 Fourteeners in Colorado. The trail is recovering naturally after being closed.

If your project team decides that natural revegetation is infeasible, a vegetative prescription must be developed. The botanist or ecologist will help you determine the plants that could serve as an appropriate mix for restoration. You also should review the scientific literature and consult with practitioners who have worked with the same plant species or in similar environments. The outcome will be the selection of plant species, treatment methods, and propagation methods "most likely to succeed" in reaching project goals. This section lays out one approach for determining the plants that will be most successful.

Consider carefully planned experimentation (otherwise known as trial and error) to cut losses and learn more about successful treatments that can be used in future projects.

3.10.2a Using the Reference Sites To Develop Plant Prescriptions

The vegetative characteristics of the reference site should be compared to those of your restoration site. Attributes to compare include the species represented, their relative abundance, distribution patterns, and age classes. Observe the stand structure; note the mix and spatial distribution of trees, shrubs, grasses, forbs, lichens, and mosses (figure 3–97). Note the growth forms of the various species present, paying special attention to species that appear to spread underground or establish freely from seed. If the site being treated is not homogenous, observe the relationship between changes in vegetative characteristics and subtle changes in site characteristics, such as full sun versus partial shade, or changes in slope or aspect. If the reference site itself has been disturbed and revegetated, examine how the successional transition occurred.

Figure 3–97—Learn to recognize vegetative patterns that form separate plant communities. Even within a meadow, the vegetation type will change based on factors such as slope, aspect, soil depth, and soil moisture. This meadow is in the San Juan National Forest, CO.

The plant communities found on your reference sites serve as a pharmacopeia, from which you can select appropriate plant species for restoration. Conceptually, the process goes like this: you want to replace the dominant species found on your disturbed-but-revegetated reference site and introduce at least some of the dominant species found on your undisturbed reference site. Those dominant species may be problematic for restoration because of limiting factors or challenges in working with the plants themselves. In that case, you will identify the early- to mid-seral species that lend themselves to propagation and outplanting, even if they are not dominant. You also will think about how to restore the stand structure so that the site supports an appropriate mix of growth forms and mimics a natural appearance, while addressing any additional limiting factors and design concerns.

The following four steps will help you translate the plant community found on the reference site into a vegetative prescription for your restoration site.

1. **Investigate the feasibility of propagating dominant species found on the disturbed-but-revegetated reference sites**—There are a couple of ways to identify dominant species. Look at species dominance on the reference sites you have chosen—which species are represented in the greatest numbers? Also look at the plant association type—a vegetative classification scheme that categorizes dominant overstory and understory species. These two methods serve as a check-and-balance system for species selection. The reference site will show you which plants are really there, but the plant association type will help you see the site in terms of the broader landscape.

   Some dominant species may pose challenges for propagation and restoration. While it is worthwhile to include propagation of these species in your prescription, you may not be able to rely on their reestablishment. In general, upland shrub species are more challenging to reestablish than graminoids (grasses, sedges, and rushes) and forbs.

2. **Investigate the feasibility of propagating early- to mid-seral species found on the disturbed-but-revegetated reference site**—The theory of vegetative succession is that early-seral species (lichens, mosses, graminoids, and some herbaceous plants) develop site conditions allowing mid-seral species (herbaceous species and some shrubs) to invade, which further develop site conditions allowing late-seral species (some shrub species and trees) to invade. This is a grossly oversimplified textbook example of Type I Succession (Smith 1980). In reality, your project environment could have trees or shrubs that behave as early-successional species. For instance, bitterbrush (*Purshia tridentata*), a shrub, can establish itself on loose, bare soils. Your reference site has been chosen because, after considering soil conditions and other limiting factors, you gauged that you could reestablish this vegetative condition on your restoration site. If you can't count on reestablishing some of the dominant species, you will want to identify appropriate early- and mid-seral species to add to the mix.

A botanist or ecologist can help you identify successional patterns at your site. Identify the plants that fall into the early-, mid-, and late-seral stages of succession. For some plants, this may be general knowledge; if not, examine the project area to distinguish between disturbed sites with early-seral plant communities growing on exposed mineral soil, mid-seral communities growing where there is some soil development, and late-seral communities (often comprised of trees or shrubs). Look for species that grow both on disturbed and undisturbed sites; a number of practitioners have observed that mid-seral species hold promise for restoration, because they survive into the development of late-seral communities (Belnap and Furman 1997; Chambers and others 1984; Chapin 1992). Grasses and sedges generally colonize disturbed soils, as do plants that spread from stolons or runners (figures 3–98a, 98b, 98c, and 98d).

Figure 3–98a—Plants that spread underground often can be spotted by their trailing habit (plants may be in clumps or even in a line). Such plants are early-seral to mid-seral species that make good restoration candidates and may be resistant to trampling. Such species include bunchberry (*Cornus canadensis*).

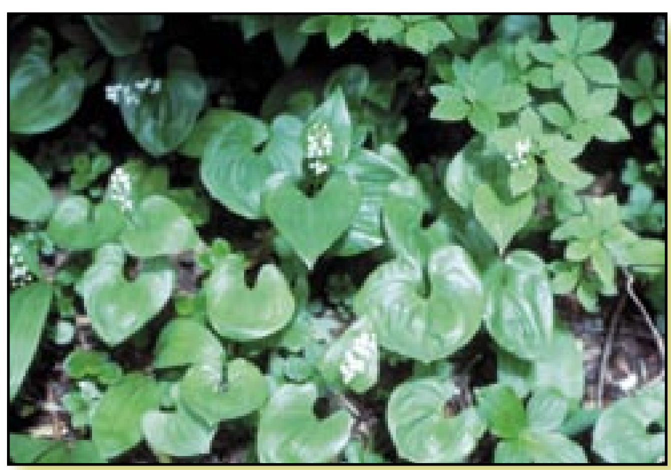


Figure 3–98b—False lily-of-the-valley (*Maianthemum dilatatum*), a good candidate for restoration projects.

Figure 3–98c—Twinflower (*Linnaea borealis*), a good candidate for restoration projects.

Figure 3–98d—Five-leaved bramble (*Rubus pedatus*), a good candidate for restoration projects.

3. **Investigate the feasibility of propagating dominant species on the reference site, especially mid-seral species**—As described in chapter 1, theories of how plant succession takes place differ. One theory, Type III Succession, presumes that once a vegetative stand becomes established, it will hold its own against "all comers" (Smith 1980), unless the stand is disturbed. If we presume this theory applies to your reference plant community, and your long-term goal represents a late-successional community, it would be prudent to introduce some of the species of your long-term goal, favoring mid-seral species that help develop conditions that might eventually support late-seral species.

4. **Identify the growth forms desired as an outcome of restoration (trees, shrubs, forbs, graminoids)**—While the graminoids and forbs are relatively easy to reestablish, they may not provide the stand structure represented in your reference sites. If your long-term goal is to have a mix of species providing ground cover, shrubs, and trees, identify the species that will move you toward this goal. It may be necessary to propagate shrubs from cuttings if seed is not readily available. For example, in the subalpine tree clumps of the North Cascades, currants (*Ribes*) are well established in the dense shade of undisturbed reference sites. The currants rarely set fruit, making it necessary to consider propagating them from cuttings.

3.10.2b Additional Limiting Factors and Design Considerations

Plants also must be selected in light of other ongoing problems such as trampling, recompaction, or continuing erosion. It is important to identify these potential factors and predict the factors that will represent the most difficult problems. Refer to appendix A, *Treatments To Manage Factors Limiting Restoration*, for additional advice on selecting plant species to help address your project's constraints. This appendix lists specific plant types and propagation methods used to address a number of extreme conditions that make it difficult to reestablish vegetation.

The nature of the disturbance may vary within the project area, requiring you to vary the species used for restoration. For example, the cut roadbeds may support different species than the fill slopes because of the differences in soil depth. In arid environments, grasses have deeper root systems than shrubs; a grassland that loses soil may support nothing but shrubs in the future (Belnap and Furman 1997).

Addressing Trampling in a Vegetative Prescription

Examining current human uses may further define limits to restoration and guide the selection of certain plant materials and propagation methods. Would continued human use of the project location prevent recovery of the desired plant community? Activities to consider might include walking, camping, off-highway-vehicle use, commercial grazing, or recreational use of packstock. Decide which of these activities will be removed through the project design, and which will be compensated for by selecting certain plant materials or types of treatments.

In areas with continued recreation or livestock use, it may be important to select plants that can withstand trampling.

Characteristics of Plants That Can Withstand Some Trampling (Hingston 1982)

Plants that can withstand trampling generally:

- Are low-growing rather than erect
- Are tufted
- Are armed with thorns, prickles, or spines
- Have leaves in a cluster at the base of the stem (basal rosette)
- Have stems that are flexible rather than brittle or rigid
- Have small, thick leaves
- Can grow from the base of the plant as well as the tips of the stems
- Have flexible leaves that can fold under pressure
- Are perennials that can regrow from buds beneath the soil's surface where they are protected from trampling
- Can reproduce vegetatively from suckers, stolons, rhizomes, or coring, as well as sexually through seeding
- Grow rapidly
- Can reproduce despite trampling

Addressing Visual Concerns

Selected plants need to be harmonious with landscape patterns and features. For example, trees or shrubs may be selected to hide a landscape feature, such as a gully.

Addressing Erosion Control

Plants also may be selected for their ability to help control erosion. A mix of growth forms provides more erosion control. The two main types of roots are taproots and fibrous roots. Taprooted plants (such as carrots and dandelions) have a large central root with finer lateral (side) roots. Taproots act like an anchor to stabilize soils. Taproots also help break up soil compaction and provide a means for water to percolate deeper into the soil. Plants with fibrous roots (such as grasses) spread a mass of fine roots that stabilize the surface of the soil better than taproots. The two types of roots can complement each other. Trees and shrubs are more deeply rooted than grasses and herbaceous species. A combination of all these growth forms can help stabilize eroding sites.

Plants that root or become established quickly also help stabilize erosion. Refer to table 3–8 in section 3.4.9, *Bioengineering Applications*, for a list of riparian species that root readily where soil moisture is abundant. These species can be used to build living structures to stabilize riparian sites. These techniques were described in more detail in section 3.4.9a, *Selecting and Installing Bioengineered Structures.*

In environments where native plants become established slowly, such as the subarctic, sometimes a sterile hybrid plant, such as rye, is used to provide roots that will stabilize the surface (Densmore and Vander Meer 1998). The use of sterile hybrids and other nonnative cultivars was discussed more fully in section 3.10.1d, *Nonnative Plants, Agronomic Varieties, or Native Cultivars.*

Adding Nitrogen-Fixing Plants, If Appropriate

Many restoration projects benefit from the use of native nitrogen-fixing plants (figure 3–99). These plants have a symbiotic relationship with bacteria that convert atmospheric nitrogen into a form that can be used by plants. The bacteria live in easily observed nodules found on the roots of the host plant. Nitrogen fixation is common in many species in the pea family (Fabaceae), as well as some other species. If plants that fix nitrogen are in the project area, they are likely to be included in the mix for propagation. If so, it will be necessary to inoculate the disturbed soil with bacteria (see section 3.2.5c, *Soil Bacteria*).

Figure 3–99—Plants in the pea family (such as this lupine growing in subalpine meadows in the Cascades, above) cohabitate with Rhizobium, a bacteria that lives in root nodules (below). The Rhizobium bacteria convert atmospheric nitrogen into a form plants can use, improving soil fertility.

Genera That Include Some Nitrogen-Fixing Species (Barbour and others 1987; Hingston 1982)

- *Alnus*
- *Casuarina*
- *Ceanothus* (figure 3–100)
- *Cercocarpus*
- *Colletia*
- *Comptonia*
- *Coriaria*
- *Discaria*
- *Dryas*
- *Eleagnus*
- *Hippophae*
- *Luetkea*
- *Myrica*
- *Purshia*
- *Rubus*
- *Shepherdia*

Ceanothus prostratus

Figure 3–100—Many species of ceanothus, found throughout the drier regions of the Western United States, fix atmospheric nitrogen. Mahala mat (*Ceanothus prostratus*), which has striking blue flowers, ranges from the Sierras and western Nevada north to southern Washington. Drawings courtesy of the University of Washington Press (Hitchcock and Cronquist 1976).

3.10.3 Determining Propagation Methods for Your Site and Species

The costs and success rates of different methods of propagation vary dramatically. Helpful information can be found in a variety of sources. The USDA Natural Resources

Conservation Service has developed a comprehensive national plants database that is on the Web at *http://plants.usda.gov/*. Additional helpful Web sites are listed in chapter 5. The propagation requirements of many species can be found in the scientific literature and in books on propagating native plants. Some recommended references include:

- *Growing California Native Plants* (Schmidt 1980)
- *Propagation of Pacific Northwest Native Plants* (Rose and others 1998)
- *Seeds of Woody Plants in North America* (Young and Young 1992)
- *Native Plant Propagation Techniques for National Parks* (Link 1993)
- *A Native Hawaiian Garden: How to Grow and Care for Island Plants* (Culliney and Koebele 1999)
- *Grass, Grass-like, Forb, Legume, and Woody Species for the Intermountain West* (Ogle and others 2003)

Subject-area experts often are happy to share what they have learned; seek the advice of other restorationists, native plant growers, or the technical support staff at the USDA Natural Resources Conservation Service Plant Material Centers.

Appendix A, *Treatments To Manage Factors Limiting Restoration*, lists a variety of potential treatments, including plant types and propagation methods. Appendix B, *Propagation and Establishment Requirements for Selected Plant Species*, contains species-specific information on propagation methods and plant establishment. The next section describes in more detail the field techniques for onsite propagation and for collecting plant materials for offsite propagation.

If successful, onsite seeding with local native plants is the least expensive method of propagation and tends to do the best job of providing genetic diversity. In many environments, including arid lands and in the subalpine zone, onsite seeding has not been very successful. Transplanting wildlings (wild plants removed from one area and transplanted to another) or other methods of onsite vegetative propagation can be fairly economical, especially if volunteer labor is available. However, these methods tend to harm the collection areas. Projects that disturb areas nearby may provide an opportunity to transplant materials. Not all species transplant well. Large plants and taprooted plants are especially challenging to transplant.

3.10.3a Seed-Increase Programs

Offsite propagation methods, such as seed-increase programs (also called a grow-out) or nursery-grown planting stock, are more expensive than seeding with local native plants or transplanting. In many cases, offsite propagation is the only viable option. Seed-increase programs are useful if a large amount of seed is needed. A relatively small amount of seed (such as several pounds or a kilogram or two) is grown as a seed crop on a relatively small plot (for instance, 1 acre or 0.4 hectare) by a farmer or nursery (figure 3–101). This approach is especially useful when planning for rehabilitation of roads, slope stabilization following wildland fires, and so on.

Seed-increase programs require 2 to 5 years to produce an adequate seed crop. Typically, the seed from the first crop is sown to produce a larger second crop, increasing the volume of seed. The cost of the seed produced goes down each year, but each successive crop runs an increased risk of genetic shift, because the growing conditions will favor

Figure 3–101—If a large quantity of seed is needed for restoration, consider a seed-increase program. A relatively small amount of seed is grown in an agricultural setting, such as at the Forest Service's J. Herbert Stone Nursery in Central Point, OR, and harvested to provide more seed.

plants that respond well to agriculture.

Genetic shift can be minimized by mimicking natural growing conditions as closely as possible and by having successive harvests of ripe seed. The USDA Forest Service's Pacific Northwest Region has a native plants program that is using seed-increase programs on a number of forests.

3.10.3b Propagation Methods and Stock Types

For nursery-grown plants, it is important to identify the propagation method and stock type. Propagation methods commonly in use for native plant production include growing from seed, various types of cuttings, divisions, layering, or tissue propagation.

The stock type is a combination of the length of time a plant is grown in a nursery before being outplanted and the method of growth (bareroot or different sizes of containers). Outplanting is when a plant is taken from the nursery to be planted elsewhere. Determining the appropriate stock type by species is a very important step in the planning phase. For each species, the appropriate stock type will depend on the project goals as well as known or inferred information on species propagation success and plant establishment once stock has been outplanted (refer to appendix B, *Propagation and Establishment Requirements for Selected Plant Species*, for species-specific information).

Consult with professional growers or other practitioners to help determine the best stock type. In some cases, selecting several stock types may enable the practitioner to hedge against losses or to provide an array of plant sizes mimicking the natural condition at the project location. The stock types are listed below in relative order of expense (Potash and Aubry 1997):

1–0 Ship: A bareroot seedling grown for one growing season in a nursery bed. Many species perform well in outplanting, including many riparian species and shrubs. Most species are started from seed, although some can be grown from cuttings.

Plug: A containerized seedling typically grown for one growing season. Outplanting performance is similar to 1–0 ship. Seedlings can be propagated from seed or cuttings. Cuttings are much more expensive. The containers come in many sizes, depending on the size of seedling that is needed. Generally, the bigger the container size, the better the seedling will perform. This stock type is good for rocky soils where it is difficult to excavate a hole for a large root system. Because the plant is in a rooting medium, there is more flexibility in the timing of outplanting than with bareroot stock.

2–0: A bareroot seedling grown for two growing seasons in a nursery bed, producing a bigger seedling than 1–0 ship or plug stock types. A conifer seedling grown as a 2–0 generally does better than plug and 1–0 ship seedlings on harsh, dry sites.

1–1: A bareroot seedling that is transplanted to a nursery growing bed after one growing season. It is grown for a second year and then lifted as a bareroot plant for outplanting. Generally, these seedlings have a thick stem and a very massive, fibrous root system. On highly productive sites, these seedlings grow very quickly, staying above competing vegetation. Because of their exceptional growth potential, they often are used in hot, dry areas or in areas where animals damage seedlings.

Plug–1: A bareroot seedling grown as a plug the first season and them transplanted to a nursery bed for another year. The performance and uses of a plug–1 seedling are similar to those of a 1–1 seedling.

2–1: A bareroot seedling grown for two seasons in a nursery bed and transplanted into a nursery bed for another year. This stock type can be used for species that are very slow growing. For faster growing species, the shoot-to-root ratio can be high, which means that the root system may not support the shoot, causing poor performance when the seedlings are outplanted.

3–0: A bareroot seedling grown for three seasons in a nursery bed. This stock type is used for slow-growing species.

Large containers: A seedling that usually is grown for more than one growing season in a 1- to 4-gallon (3.8- to 15-liter) or larger pot. Because of their large size, seedlings of this stock type appear established when planted and can withstand some of the abuses that are common in heavily used recreational sites.

Container Sizes

In the wet forests of western Washington, plants destined for restoration in wilderness are generally propagated in 2-inch (50-millimeter) pots (figure 3–102). Plants that need more than one growing season before being outplanted may be transferred to larger pots.

Figure 3–102—Wilderness restorationist Greg Shannon transfers sedge seedlings started in flats to 2-inch (50-millimeter) pots where they will grow for 3 more months before planting. The 2-inch (50-millimeter) pots provide a plug that is large enough to be planted in areas with dependable precipitation.

For drier sites, long planting tubes such as the 8-inch (200-millimeter) or longer super cell, will make it possible to outplant seedlings with a deeper root system. Most native plant nurseries use this approach (figure 3–103).

Figure 3–103—Methow Natives (Winthrop, WA) and many other native plant nurseries use long tubes for growing plant stock with deeper root systems. This approach works well when establishing plants on drier sites and in areas where irrigation is a problem.

The restoration staff at Joshua Tree National Park in California uses a 36-inch (914-millimeter) "tall" pot and an 18-inch (457-millimeter) "half tall" made from 8-inch- (200-millimeter-) diameter PVC pipe with a removable mesh bottom (figures 3–104a and 104b). Creosote bushes or other shrubs grown in these pots for 6 months or so can be transplanted easily into machine-augered planting holes. Their root systems are deep enough to reach the available soil moisture. Plants grown in large containers such as these are the most expensive, but sometimes stock from large containers is the minimum tool necessary to assure outplanting success.

Figures 3–104a and 104b—To establish native vegetation on the exceedingly dry Mojave Desert, the staff at Joshua Tree National Park, CA, developed 36-inch (914-millimeter) "tall" containers and 18-inch (457-millimeter) "half talls" (top). The mesh bottom is removed before the containers are planted (bottom). The container is removed by lifting it from the planting hole.

Chrysanthemum leucanthemum

Figure 3–105—Although oxeye daisy (*Chrysanthemum leucanthemum*) is prolific and easily established (even pretty), you wouldn't want to inadvertently select this noxious weed to restore your restoration site. One of the authors has been pulling oxeye daisy seedlings in her garden for 15 years and still hasn't depleted the seedbank. Drawings courtesy of the University of Washington Press (Hitchcock and Cronquist 1976).

3.10.3c Noxious Weeds and Other Nonnative Invaders

Unfortunately, noxious weeds have thoroughly invaded some remote backcountry and wilderness areas. You could unknowingly identify a weedy species (figure 3–105) as having potential for revegetation. The botanist on your team will help you avoid this mistake. Weedy species have great potential—that's why they're a problem.

3.10.4 Concluding Thoughts on Plant Selection

Selecting plant species involves careful consideration of project goals, site capability, and methods to ameliorate adverse conditions. Very few projects fully succeed in replacing all elements of the predisturbance plant community—its species composition, structure, and function. It is easy to become discouraged, because deep down we all recognize the importance and desirability of restoring the predisturbance community. A careful planning process, such as the one described in this chapter, will help you make the best call possible, given site conditions, technological capabilities, and the project budget.

3.10.5 A Comparison of Propagation Methods

Growing plants from seed is the only form of propagation that results in sexual reproduction with a wide array of genotypes represented in the propagated plants. The vegetative forms of propagation produce clones of the donor plant, limiting the genetic diversity of the restored plant community. However, some species are not easy to grow from seed. In such cases, vegetative propagation techniques become the solution for providing adequate and affordable plant materials. Tables 3–11 and 3–12 summarize the pros and cons of various onsite and offsite propagation methods.

Table 3–11—The advantages and disadvantages of different onsite propagation methods.

Onsite propagation method	Advantages	Disadvantages
Common to all methods of onsite propagation.	All methods, if successful, are less expensive than offsite propagation and generally eliminate the time required to propagate plants.	Plant materials for propagation often are limited. Success can be limited in many environments.
Onsite seeding—Native seeds are collected and sown directly onto the area to be restored.	If successful, this method is relatively inexpensive. For small areas, onsite seeding can be accomplished without special equipment. Most seeds would not require special treatment to break dormancy. Treatment can be done without delay while plants are growing in a nursery. The genetic diversity of the plant community is maintained.	Germination rates are low in many environments, such as in arid lands and in the subalpine zone. Seeds sown on arid lands could be dormant for years before rainfall is adequate to induce germination. Seed production and viability can vary tremendously from year to year. Seed may have to be collected several years in advance. It can take many years for seedling plants to mature and establish stand structures similar to the target plant community. Rodents, birds, or insects can eat the seeds.

Table 3–11 continued

Onsite propagation method	Advantages	Disadvantages
Onsite rooting of cuttings—A limited number of species will root when the cuttings are planted directly in moist soil on the area to be restored.	If successful, this method is relatively inexpensive. Treatment can be done without the delay of growing plants in a nursery. Onsite rooting of cuttings works well with bioengineering methods of slope stabilization. Larger plants are more visible at the restoration site and could deter use.	This technique requires that the soil be moist long enough for the seedling to develop an adequate root system; generally limited to riparian areas. Success is limited to genera and species that root readily, such as willow (*Salix* spp.), some dogwoods (*Cornus* spp.), cottonwood and poplar (*Populus* spp.), some alder (*Alnus* spp.), some elderberry (*Sambucus* spp.), and honeysuckle (*Lonicera* spp.). Plant material for cuttings may be limited. New plants are a clone of the parent plant, limiting genetic diversity. This technique is more labor intensive than seeding.
Onsite divisions—Species with fibrous root systems, rhizomes, or stolons can be dug up, broken apart at the roots into multiple plants, and transplanted. *Sprigging* is a variation where small plant parts are scattered across the site and raked or tilled into the soil without planting each part individually.	If successful, this method is relatively inexpensive. Treatment can be done without the delay of growing plants in a nursery.	Plant material to be broken apart may be limited. New plants are a clone of the parent plant, limiting diversity. Onsite divisions require more labor than seeding. Onsite divisions can damage undisturbed areas where material is collected. Holes need to be filled after transplants are dug up.
Onsite layering—The attached branch or shoot of a parent plant is rooted.	Works well on trails that have shrubs growing alongside the trail.	Success is limited to species that layer or root readily. Onsite layering generally is useful only where appropriate shrubs, trees, or vines are growing alongside the site being treated. The new plants are a clone of the parent plant, limiting diversity.
Transplanting wildlings—Native local plants are dug up and transplanted.	Ground-disturbing projects that are occurring nearby, such as trail or road construction, can be a source of transplants. Local plants are adapted to the area. This technique produces results immediately with more mature plants. Larger plants are more visible at restoration site and could help deter use while the site is recovering.	Not all wildlings will transplant well, especially large plants, plants with taproots, or plants with very specific requirements for establishment. Unless transplants are salvaged, transplanting damages the undisturbed area where the transplants are collected. Salvage operations often require holding plant materials until they can be replanted. This increases the labor required and can complicate the logistics.

Table 3–12—The advantages and disadvantages of different offsite propagation methods.

Offsite propagation method	Advantages	Disadvantages
Common to all methods of offsite propagation. Nursery stock types range from bareroot plants, to small containers or plugs, and to larger containers. The preferred stock type is based on predicted survival requirements and project goals.	For many environments, offsite propagation allows for much more rapid stabilization of the site and establishment of plants at the site. Offsite propagation is the best way to propagate plants that are difficult to establish with onsite techniques. Offsite propagation prevents damage to the collection site caused by overcollection of materials that are needed for most onsite propagation techniques.	All offsite propagation techniques require varying amounts of facilities, equipment, staff expertise, and daily care, raising costs considerably above those for onsite treatments. The time needed to propagate species may range from 6 months to several years. Pathogens or other nonnative insect or plant species may be introduced. Transportation of plants to roadless project locations increases the cost and adds logistical difficulties. Plants may need to be held at the nursery until they can be outplanted. This increases logistical difficulties and the possibility that plants may not survive. Animals are most likely to eat fertilized nursery-grown stock once it's outplanted.
Offsite seedlings—Native seeds are collected and sown into nursery beds, flats, or containers.	Offsite propagation can produce better germination and survival rates than onsite seeding. The diversity of the plant community is generally maintained.	Seed production and viability can vary tremendously from year to year. It may be necessary to collect seed several years in advance. Offsite germination and growing conditions may select for or against certain traits, changing the genetics of propagated plants.
Offsite rooting of cuttings—A portion of the plant, usually the stem, is cut off and rooted. Different species respond to different types of cuttings.	Offsite rooting of cuttings is a good method when seed is unavailable or difficult to work with. A wide variety of species will root from cuttings. Many species grow faster from cuttings.	New plants are a clone of the parent plant, limiting diversity.
Offsite divisions—Species with fibrous root systems, rhizomes, or stolons can be dug up, broken apart at the roots into multiple plants, and then transplanted.	Offsite divisions is a good method when seed is unavailable or difficult to work with. Divisions can be made over and over in a nursery until it is time to outplant the seedlings.	The new plant is a clone of the parent plant, limiting diversity.

Table 3–12 continued

Offsite propagation method	Advantages	Disadvantages
Seed-increase programs—Native seed is collected onsite and grown offsite to produce a seed crop.	Seed-increase programs are the only way to multiply a small amount of seed into a large amount. This technique is best used when a large quantity of seed is needed. Seed can be used as soon as it is produced, or stored until it is needed for fire rehabilitation or mine reclamation.	The plant's genetic makeup can shift based on growing conditions, harvest timing and methods, and seed-cleaning techniques. It is difficult not to introduce weed seed.
Tissue propagation—Plants are propagated from very small pieces of plant material, such as the growing tips of shoots.	Tissue propagation is generally used with species that are difficult to propagate or with rare plants with limited vegetative material available for propagation.	This technique is very expensive. New plants are a clone of the parent plant, limiting diversity.

Project planning should include consultation with others having experience with the same species or in similar environments. Even slight changes in environmental conditions can change the outcome of a treatment.

If plants are propagated offsite, they will need to be slowly hardened off before outplanting. Hardening off is the process of weaning plants off the optimal growing conditions provided in the nursery so they will survive once they are planted in the wild. Hardening off usually involves reducing water and shade, increasing or decreasing ambient temperatures, and reducing fertilization. Many species are top pruned or even root pruned several weeks before outplanting to increase the root-to-shoot ratio. The hardening-off process usually occurs at the nursery, although sometimes restorationists are required to take care of this crucial step themselves (figure 3–106). In some cases, the plants are hardened off at the restoration site.

Bareroot stock is hardened off to induce dormancy. Plants are held in a cool, dark, moist environment until they are transplanted. If USDA Forest Service tree coolers are available, they are ideal for storing bareroot stock.

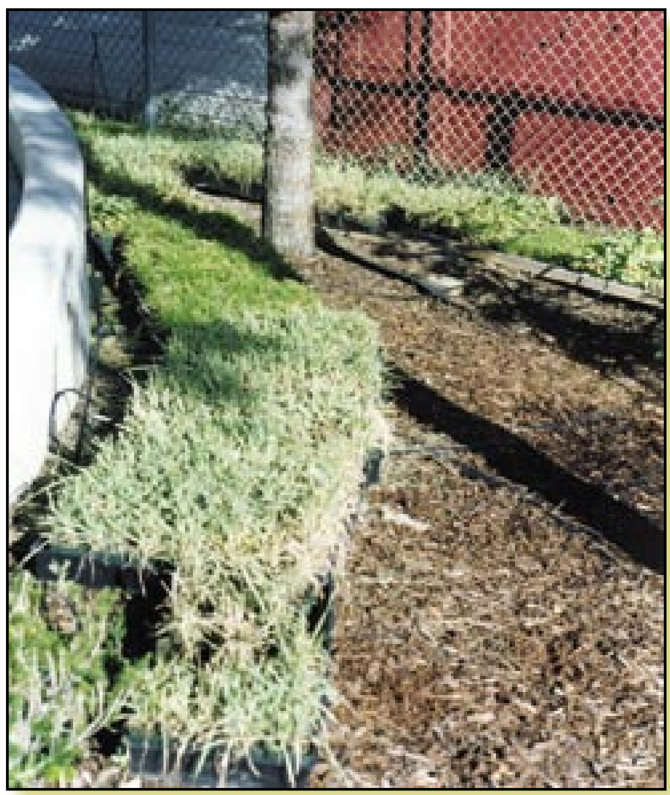


Figure 3–106—Before plants used in restoration are outplanted, they are hardened off, gradually increasing their exposure to the conditions they will experience after they have been planted in the wild. As can be seen on these sunlit sedge flats, their foliage was cut back to increase the root-to-shoot ratio, increasing the chance that they would survive. These plants were stored behind the Leavenworth Ranger Station in Washington for 3 months before outplanting.

3.10.6 Plant Collection Principles

The genetic principles for collecting plant material outlined earlier in this guide should be followed, including adhering to local or agency genetic policies. In the absence of such a policy, the following guidelines are conservative enough to preserve the genetic integrity of plants in wilderness or other wildland project locations, while assuring adequate representation of an array of genotypes to establish a genetically diverse population.

Plant materials, such as seed, cuttings, or wildlings should be collected from throughout the entire plant collection zone, taking equal amounts from at least 30 to 50 unrelated individuals (figure 3–107). The plant collection zone can extend 250 vertical feet (about 76 meters) above and below the project location. Start collections at the upper elevation limit to assure that some of cold-adapted individuals are included. Ideally, in wilderness, plant material should come from the same subbasin. If plant material is scarce, collecting plant material within the same watershed is considered acceptable.

Figure 3–107—Wilderness restorationist Greg Shannon collects cuttings from heather for propagation. All cuttings taken from an individual plant will be a clone of that plant, making it important not to collect too many cuttings from one plant.

Propagules should be collected from plants that differ in appearance and are found in different microhabitats, if possible (rather than only from the most robust-looking individuals on the most ideal sites). Parent plants that are diseased or that have insect infestations should be avoided. If the site to be treated is unusually harsh, seek out propagules from plants found on sites that are just as harsh. To avoid genetic bias, avoid overharvesting stands that are unusually lush.

Nursery propagation methods are not described in detail in this guide. Many books and publications on propagation techniques and the propagation of native plants are listed in the references. The interest and commitment to using native plants is rising within agencies, which means that restorationists are more likely to have professional support to help them select propagation methods and develop sources of locally adapted native species.

If plants are going to be propagated offsite, consult with the grower. Questions to ask the grower include how to collect and prepare plant material, how much to collect, and how to ship the material to avoid injuring it. In addition, the plants may need to be stored or held over until the next growing season before outplanting. For an additional cost, some growers can do so. Others may not wish to.

If nursery-grown stock is to be inoculated with soil organisms, the plant collector will probably collect inoculum at the same time that the plant materials are collected.

3.10.7 Preventing Further Damage to the Project Area

Once the planting begins, take care to avoid further damage to the project location, including the freshly prepared site and the vegetation surrounding it. Have a plan in place for work crews to follow, including how crews will travel in and around the work site. Select a staging area, preferably one that has already been impacted, or one in a resilient location. If the work crew is to camp, select a campsite that can withstand the impact of their stay. If the area receives recreational use, the campsite should be isolated from public view. Crews should be taught low-impact practices before they begin their work.

Once the planting bed has been prepared, minimize soil compaction caused by foot traffic or machinery. It often helps to identify a travel corridor in the site being treated, perhaps even laying out stepping stones. Indoor-outdoor carpet, scrim, or worn out foam sleeping pads, make good walkways to protect meadow vegetation from excess trampling. Ladders have been used to access steep, eroding banks to avoid walking up and down the slope.

Additional Information on Plant Propagation

For additional information on plant propagation, consult *Plant Propagation: Principles and Practices* (Hartmann and others 1990) and *Plant Propagation* (Browse 1979).

3.10.8 Working With Seed

Seed crops can vary widely from year to year, with some species going for years with no seed or fruit (in which case a different propagation method may need to be chosen). Because of this variation, it may be necessary to collect and store seed for several years to have an adequate supply for a restoration project.

3.10.8a Seed Collection

The seed of many plant species ripens and drops quickly. With some species, it is not uncommon to leave the project area for a few days and come back to find that all the seed has completely dropped. If seed collection is important, the ripening seed must be monitored carefully. Characteristics to look for include: capsules beginning to open, pods beginning to darken, seed that is swelling and becoming hard instead of pulpy when squeezed, seed that drops from the plant when disturbed, grass heads that are beginning to cure, fleshy fruits that are ripening, and so forth (figures 3–108a and 108b). Some fruits explode to disperse seeds. These fruits should be harvested when the pod is nearly ripe, before the pod explodes. Pods or capsules can be stored in paper bags so seeds will not be lost when the capsules explode. Collect cones when they have turned from green to brown, but before they have opened.

Figures 3–108a and 108b—Partridgefoot seed (top) is collected by District Ranger Becki Heath, a dedicated wilderness line officer (bottom). Partridgefoot (*Leutkea pectinata*) seed is easy to collect by leaning the stems into the opening of a bag and tapping the stems gently. Seed is ripe when the flower stalks begin to turn reddish brown and the capsules open.

Seed collection should occur throughout the ripening period, to assure genetic diversity. With some species, collection can begin during the latter part of the "soft dough" stage, which can be recognized by squeezing the seed between the thumb and forefinger and squeezing out the contents. In the "hard dough" stage, the seed cannot be squeezed open and is generally too hard to bite open.

The ripening period for a particular species may not be consistent from year to year. In mountainous environments, the initiation of flowering often is based on temperature, which can vary from one year to another, sometimes delaying flowering for weeks. Seed will mature earlier or later depending on the initiation of flowering. In desert environments, flowering often follows rain, with seed production close behind.

Do not deplete an area of more than 50 percent of its seed. This generally is not a problem, because most collectors drop seed when collecting it or don't harvest entire stands. Be careful not to contaminate native seed by inadvertently collecting weed seed. Seed collected throughout the plant collection zone at a given site or sites can be combined by species into a seed lot (figure 3–109).

Figure 3–109—Seed collected throughout the plant collection zone at a given site or sites can be combined by species. This combination is a seed lot that will be documented on a seed collection form.

Most projects in wilderness areas and remote sites are relatively small, allowing seed to be collected by hand. A number of simple comb-like tools can be fabricated to make the collection go faster. For small collections, collectors can use small paper bags to hold the seed. For larger collections, collectors can wear fruit picking bags, carry plastic pails, carry metal trays like baking pans, or use similar devices. It is rarely feasible to use machinery when harvesting native seed from the wild (Young and Young 1986).

The following techniques have proven successful for harvesting seed by hand:

Cutting—Use scissors or a sickle to remove seed heads. When using a sickle, gather the stems with seed heads in one hand, and cut the stems as close below the heads as possible. Wear leather gloves to protect your hands. This technique works well with herbaceous plants and grasses.

Stripping—To strip seed, pinch fingers and pull them over the seed head, allowing the seed to drop into a container. This approach works with graminoids, forbs, and some shrubs when the seed is ready to fall from the plant. Gloves will protect your fingers.

Beating and Shaking—Plant stems can be held and shaken over a tray or tarp or beaten by hand or with a paddle. For large collections, tarps are less efficient because of the time needed to spread them out. It is faster to hold a metal tray under the branch or stem.

Pruning—When other methods are not successful, seed can be removed from tall shrubs or trees by pruning limbs bearing seed.

3.10.8b Initial Processing of Seed

Seed will mold and rot quickly if it is not cured properly. Collectors should spread the seed out to dry for about a month in a warm (not hot) location. Seed that is small will dry in less time. Small quantities of seed can remain in brown paper bags while drying. The mass of seed should be pushed to the edges of the bag to maximize air circulation. If seed is cured outdoors, it must be protected from animals that eat seed and from excess heat, precipitation, and frost.

Dry cones by spreading them out in a single layer on racks in a warm place with good air circulation. Turn the cones every few days to prevent them from molding. Cones will open in a few weeks or so (Sound Native Plants 1994).

Seed processing and cleaning is a rather involved science. Professional growers use a wide array of equipment to separate the seed from the plant material and to clean the seed. Professional growers can help, particularly with seed that is difficult to clean, but their services add to the cost. For many species, field practitioners can do part or all of the cleaning themselves, being careful to retain as much of the viable seed as possible to preserve genetic diversity.

Seed processing and cleaning needs to be more thorough if seedlings are to be grown in a nursery or resown with machinery. But even if the seeds will be sown onsite, excess plant matter mixed in with the seed can cause the seed to deteriorate and increase the time needed for the seed to break dormancy. For instance, the awns on the seed of some species of grass have a chemical inhibitor that maintains seed dormancy.

3.10.8c Hand-Processing Seed

Rub the plant parts to free the seed from its covering. The plant material can be rubbed on a wire screen (figure 3–110) or between blocks of wood or bricks. Plant material can be put inside a bag or a rubber tire tube and kneaded underfoot to abrade it. One restorationist suggests placing a bag with seed and several pairs of shoes in a dryer and tumbling them with no heat. You may want to be careful whose dryer you pick for this method!

Chaff can be separated from heavier seed by blowing the seed with a fan while it is being rolled down a screen or poured between two containers. An alternative method is to put plant parts in a tub and run a string-type weed eater in the tub to separate the plant materials from the seed. Most seed will work its way to the bottom of the tub.

Seeds can be extracted from fleshy fruits by crushing the fruit on a screen with a rolling pin, or by running it through a fruit press (figure 3–111). An alternative method is to macerate the fruit by adding about 50 percent water by volume and running the material through a blender that has its blades taped to reduce damage to the seed. The blender's blade can be replaced with strips of rubber, which will reduce the seed that is damaged. Allow the resulting slurry to sit until the pulp has separated from the seed; this may take a few minutes to a few days. Fleshy fruits that have dried out can be run through a grain mill with a coarse setting.

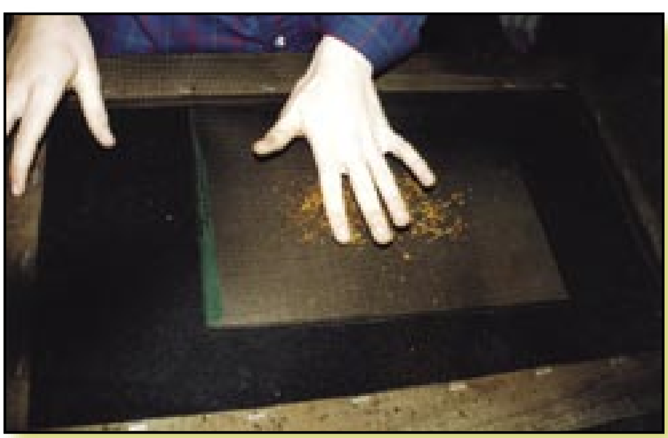


Figure 3–110—Plant material can be rubbed on a wire screen to remove the seed.

Figure 3–111—Seed can be extracted from fleshy fruits by crushing the fruit on a screen, by macerating the fruit with water in a blender, or by running dried fruit through a grain mill with a coarse setting. This photo shows black twinberry (*Lonicera involucrata*).

Some seed, such as those from cones, pods, or open seed heads, can be placed in bags and trod underfoot. Tree nurseries have more thorough methods for removing seed from cones. Any wings on the seed need to be removed before the seed is sown.

The seed of most species requires a period of afterripening, ranging from one to several months when the embryo matures inside the seed. With some species, afterripening takes place inside the fruit. This adaptation prevents seed from germinating prematurely during inhospitable growing conditions, such as during the winter or the extreme heat of summer.

If plants are to be grown professionally, seed should be shipped as soon as it has been cured to prevent seed mortality. Ship early in the work week to avoid weekend delays.

3.10.8d Seed Storage

Practitioners may choose to store small quantities of seed, particularly if the seed will be used for onsite seeding. Seed can be destroyed by insects, fungi, or ice crystals during storage. For most seed, proper drying coupled with storage in a cold, dry environment will maximize seed viability (figure 3–112).

Figure 3–112—Once seed has been air dried thoroughly, the greenhouse staff at Joshua Tree National Park, CA, stores seed lots in a freezer.

Young and Young (1986) suggest that moisture and temperature influence seed deterioration in the following way; first, each 1-percent reduction in seed moisture doubles the life of the seeds, and secondly, each 10-degree-Fahrenheit (6-degree-Celsius) reduction in seed temperature doubles the life of the seeds. If stored seed has more than 14-percent water content, ice crystals can form and destroy the embryo. Water content of less than 5 percent also seems to damage the seed.

If mold or insects are anticipated to be a problem, the surface of the seed can be sterilized with a 10-minute soak in a solution of two parts bleach to three parts water, or of 3-percent hydrogen peroxide. Follow the soaking with a thorough rinse in water. These treatments are toxic to some plant species and should be used only if they are needed (Bainbridge and others 1995). A sprinkling of diatomaceous earth also will protect stored seed from damage by insects.

The maximum temperature for drying seed is 90 to 100 degrees Fahrenheit (32 to 38 degrees Celsius). Seed must be dried in an area with low relative humidity, because the idea is to draw moisture out of the seed rather than into it. Seed needs to be dried quickly, but if it is dried too rapidly, the surface of the seed can be damaged by cracking.

Small lots of seed are stored at below freezing temperatures in sealed jars, such as canning jars. Indicator desiccants, such as colored silica packets, should be placed in each jar to absorb moisture. When the silica changes color, it is replaced with a new packet. The old packet can be renewed by heating it in an oven to drive off the moisture.

For larger seed lots, seed can be stored in moisture-proof containers, such as metal boxes with a gasket on the lid. Properly dried seeds can keep for several years when stored this way. Professional seed-processing facilities have moisture-proof storage rooms with storage conditions that are close to ideal.

3.10.8e Seed Testing

Pure live seed per pound is a measure of viability and purity, determined by a seed testing lab. Most wilderness projects probably don't need to test seed viability. Testing may not be necessary for species that have reliable seed viability. Without high-quality seed, all the time, money, and effort of preparing a site could be wasted. If professional or commercial services are involved in collecting seed, seed-increase programs, or growing seed offsite, the percentage of pure live seed should be determined. Knowing the pure live seed per pound also is important if seed mixes are being developed.

Pure live seed per pound is determined by sending about 500 seeds of a species to a seed lab for testing. Several methods are used to determine viability. Tetrazolium staining, used to determine whether the dormant seed embryo is respiring (still alive), is one of the more reliable tests for larger seeds. Tetrazolium staining also has the benefit of offering quick results for seeds that might need longer to break dormancy. Tetrazolium staining generally is not feasible with small seed (the size of grains of salt or sand). Instead, a weighted replicate germination test is used (Vankus 2004).

Each State has a seed testing program geared toward supporting the agricultural industry. Not all seed labs are equally proficient in testing native seed (Vankus 1997). To identify a reliable lab, consult with native growers or large-scale restoration practitioners.

3.10.8f Breaking Dormancy

Most seeds have adaptations that allow them to remain dormant until growing conditions are favorable for seedlings to become established. Seed dormancy can be caused by a thick seed coat, chemical inhibitors, or a combination of both. Breaking dormancy is critical to professional nurseries, which know a great deal about the requirements of many species. The practitioner needs to be aware of these basic concepts, especially in regard to preparing seed and timing onsite seeding. The methods for breaking dormancy for a number of selected species are identified in appendix B, *Propagation and Establishment Requirements for Selected Plant Species.*

In nature, plants with thick seed coats often are broken down when birds crack the seed or partially digest it. Seed may be abraded when wind tumbles it across rocks or when it is scorched by fire. If seed with a thick seed coat is sown without pretreatment, germination rates will be lower and germination will take longer.

Scarification is used to break dormancy in plants with thick seed coats. Depending on the species, the seed coat can be cracked with a rolling pin, clipped with snips, nicked with a knife, abraded with sandpaper between blocks of wood, soaked in hot water or sulfuric acid, or leached in running water (figures 3–113a, 113b, and 113c). Care must be taken to avoid damaging the tiny embryo. Sulfuric acid treatment should be done professionally, because the acid is dangerous, timing is critical, and a neutralizer is needed. Seed can be leached in water by putting seed in a cloth or mesh bag and allowing water to run through the seed lot for the correct period of time, often 48 hours. An easy way to run water through the seed lot is to put the bag of seeds inside the tank of a toilet that is used frequently.

Figure 3–113a—The seed of creosote bush (*Larrea tridentata*) needs to be leached with water to wash away chemical inhibitors stored in its thick seed coat. (Hickman 1993).

Figure 3–113b—Creosote seed is laid on wet, paper-lined trays to germinate. Germinants are carefully picked up with tweezers and planted in pots at Joshua Tree National Park, CA. (Hickman 1993).

Figure 3–113c—Did you know that creosote bush is one of the world's oldest living plants? Some creosote bush clones are 10,000 years old (Hickman 1993).

Plants with chemical inhibitors that maintain dormancy usually require cold-moist stratification. In nature, this usually happens during the fall and winter, when soil temperatures are consistently cool and moist soil is against the seed. For the practitioner planning to sow seed onsite, a fall sowing provides the best chance that the seed will break dormancy over the winter, although during some years the conditions may not allow the seed to do so. The period of time needed to break dormancy varies tremendously by species.

Professional growers induce cold-moist stratification by packing seed in a moist medium, such as peat moss, and storing the seed in a refrigerator for a set period of time. Or seed can be soaked in a net bag, which is placed inside a plastic bag and hung inside a cooler.

After dormancy has been broken, the seed begins to germinate. To germinate, a seed must imbibe water, which induces chemical changes that allow metabolism to increase. When the embryo grows, it pushes the seed open and begins to root in the soil, a process called seedling emergence if the tiny plants survive germination. Germination requirements, which include the amount of moisture, warmth or cold, and darkness or light, vary by species. The germination requirements of a particular species will influence the practitioner's choice of cultural methods.

Additional Information on Seed Collection, Processing and Storage

Two good references are *Collecting, Processing, and Germinating Seeds of Wildland Plants* (Young and Young 1986) and *Native Seed Collection Guide for Ecosystem Restoration* (Huber and Brooks 1993)

3.10.8g Onsite Seeding Techniques

Onsite seeding is a common restoration treatment. Seeding success varies, depending on the environment, weather conditions, species, and the degree of site disturbance. If successful, direct seeding is the least expensive method of restoring native vegetation and it assures genetic diversity.

Species generally respond most favorably if the seed is covered with soil, increasing the moisture available to support the emerging seedling. Seed can be broadcast on the soil surface and covered with soil, or seed can be placed directly into the soil. Most subarctic species require light for germination, an exception to the rule of covering seed with soil.

Projects in wilderness or at remote sites probably will be seeded by hand sowing (figure 3–114) or with a hand-held seed spreader, such as a Cyclone seed spreader. Larger projects outside wilderness can use equipment to broadcast seed quickly. Helicopters can broadcast seed over huge landscapes. They work well on steep or broken terrain. Machines called drillers drill small holes to a specified depth in the ground, drop in seed, and tamp the ground, producing uniform rows of seedlings. Hydroseeding mixes seed with water and sprays the mixture over the area to be treated. Hydroseeding can be very effective in temperate areas, but is not very successful on arid lands. It also requires motorized equipment, making it unsuitable in wilderness areas. Other types of equipment, such as centrifugal broadcasters (also called end-gate seeders), cast the seed 20 to 40 feet (6 to 12 meters) and use a harrow or a chain pulled behind the seeder to cover the seed with soil.

Figure 3–114—A Parmesan cheese shaker will help assure that small seed is distributed evenly. If you add the seed to fine, dry sand and put the mixture in the shaker, the seed will go farther than if you spread it with your fingers.

Some benefits achieved with machinery also can be emulated on small sites by using handtools. For example, imprinting creates microbasins across the surface of the site that catch water, retain mulch, and provide some protection from wind. Pitting creates even smaller pits about 20 inches (510 millimeters) apart and 2 to 3 inches (51 to 76 millimeters) deep with seed planted inside each pit (Belnap and Furman 1997).

Literature relating to mine reclamation, road obliteration, and other landscape-scale restoration applications describe the use of mechanized techniques for seeding. They will not be discussed further in this guide.

Once seed has been sown on the seedbed, you can lightly rake it into the soil or work it in with your fingertips. A thin layer of topsoil or compost can be added. If the soil is loose, the ground can be tamped lightly to make sure that seed contacts the soil. In sandy soil, seed needs to be planted a little deeper. A general rule of thumb is to plant seed one and a half to two times deeper than the seed diameter. For many environments, mulch will provide additional protection to emerging seedlings discussed fully in section 3.12, *Plant Protection and Establishment*. Some species require a mineral soil seedbed for establishment; practitioners at Denali National Park in Alaska have found this to be true with subarctic species (Densmore and Vander Meer 1998).

If animals are likely to eat too much of the seed, a variety of techniques can be considered to address the problem. In the Southwest, ants are major collectors of seeds. Cracked wheat can be spread before seeding to satiate the ant population (Bainbridge and others 1995). Raking seed into the soil or covering the soil with mulch will help discourage birds and rodents.

Raising the Soil Temperature To Induce Germination at Subalpine Sites

Seed is sown onto a prepared seedbed in the fall and mulched with an erosion-control blanket (figures 3–115a and 115b). When the snow has melted the following season, clear plastic sheeting is anchored over the seeded area.

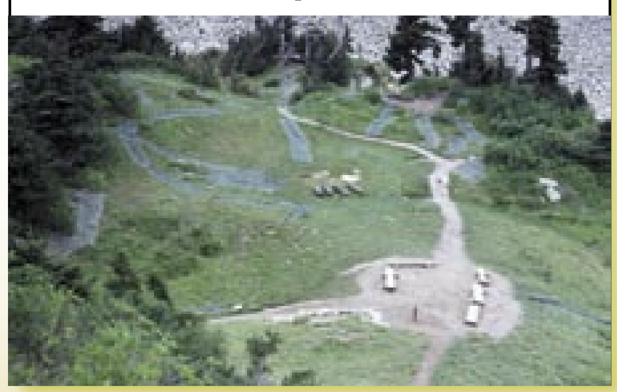
Visqueen (polyethylene sheeting) warms the soil and retains moisture, which is especially helpful when working with sedges (*Carex* spp.).

The sheeting is removed before the soil gets warm enough to kill the tiny seedlings. According to backcountry district ranger and restorationist Bill Lester, the technique of using Visqueen to enhance seedling emergence was discovered by accident in North Cascades National Park, WA. When a crew left the backcountry for their days off, they accidentally left a piece of Visqueen lying over some bare soil. When they returned, they noticed that the soil under the sheeting was covered with tiny green seedlings.

The optimal soil temperature is 85 degrees Fahrenheit (30 degrees Celsius). A soil thermometer is used to monitor soil temperature. Frequent monitoring is necessary to prevent the temperature from getting too high or the bed must be irrigated as the soil dries. Perforated landscape plastic has the advantage of ventilating heat better, which could reduce the frequency of monitoring. The sheeting is removed once seedlings emerge, or it could remain longer if temperatures remain cool (Weisberg 1993).

This is basically the same setup that is used in solarization to kill weed seeds (described previously in the soils section). The difference is in that soil temperature is maintained at about 85 degrees Fahrenheit (30 degrees Celsius), the optimal temperature for seedling emergence. Solarization allows soil temperatures to reach temperatures of 180 degrees Fahrenheit (82 degrees Celsius), which kills most germinating plants (Bainbridge 1990).

Carex spectabilis



Figures 3–115a and 115b—Warmth and moisture benefits newly seeded sedges (top). Jute netting (blue strips, bottom) helps protect seeded areas at a restoration site in North Cascades National Park, WA. Drawings courtesy of the University of Washington Press (Hitchcock and Cronquist 1976).

3.10.8h Seeding Rates

There is virtually no way to correlate the desired ratio of established plants with a seed-mix formula because of the array of variables: seed viability, time and conditions needed to break dormancy and induce germination, animals that eat seed, soil moisture, seedling survival, and so on. Seeding rates that are too low will not provide enough seedlings for erosion control or competition to keep out nonnative species, while too many seedlings may outcompete one another for limited water and nutrients. The ratio between various life forms (graminoids, forbs, shrubs, and trees) affects the establishment ratio, but the correlation is not direct. For example, on the sagebrush steppe, grasses tend to outcompete forbs, so a mix lower in grass seed may be needed unless the desired outcome is for grasses to dominate (Doerr and others 1983). In the same way, the ratio of species in a seed mix cannot be correlated directly to species establishment. Seeding rates often take years of site-specific experience to develop.

Redente (1993) suggests that broadcast seeding techniques require twice as much seed as techniques based on drilling, but that the result more closely mimics natural processes.

Seeding rates vary by the environment, species, and the viability of the seed. Seeding rates usually are expressed as seeds per square foot or pounds per acre. The USDA Natural Resources Conservation Service recommends 20 pure live seeds per square foot for favorable planting conditions. That rate may need to be increased two to four fold, based on factors such as weed competition, steep slopes, low soil moisture or nutrients, or highly disturbed soils (Redente 1993). Arid land restorationist Dr. David Bainbridge (Bainbridge and others 1995) recommends 100 to 500 seeds per yard (meter) for arid lands such as the Mojave Desert of southern California. Restorationists sow at least 133 seeds per square foot (0.09 square meter) in Mount Rainier National Park in Washington (Rochefort 1990).

Redente offers the following broadcast seeding rates for forbs and graminoids, based on annual precipitation (table 3–13). The rate needs to be higher for shrubs.

Table 3–13—Broadcast seeding rates for forbs and graminoids (Rendente 1993). A square foot is 0.09 square meter.

Annual precipitation inches (millimeters)	Pure live seeds per square foot
6 to 18 (152 to 457)	40 to 60
19 to 30 (483 to 762)	60 to 80
More than 30 (762)	80 to 120

Seed and Fertilizer Rate Conversion Factors

Pounds/acre x 1.12 = kilograms/hectare
Kilograms/hectare x 0.892 = pounds/acre
Kilograms/hectare x 0.10 = grams/square meter
Pounds/acre x 0.000367 = ounces/square foot
Pounds/acre x 0.00330 = ounces/square yard

20 pounds/acre = 100 square feet seeded with 0.05 pounds of seed

3.10.9 Working With Cuttings

When it is difficult or impossible to propagate plants from seed, cuttings are a common method of propagation. Depending on the species, cuttings can be taken from different parts of the plant: buds, stems, leaves, or roots. Determine which type of cutting is appropriate for a given species; several types of stem cuttings are the most common when propagating native plants.

Cuttings are usually rooted at a nursery, although a few genera and species lend themselves to rooting directly in moist soil at the project site. Often, these species are used to create bioengineering structures designed to stabilize slopes. Methods for bioengineering are described in section 3.4.9, *Bioengineering Applications.*

3.10.9a Collecting and Handling Cuttings

The plant collection guidelines described at the beginning of this section are used to identify and tag parent or donor plants. This must be done while leaves are on the stem to assure accurate species identification. Some plants, such as willows, have separate male and female plants. It is important to collect cuttings from plants of each gender to establish a population that can reproduce.

Collect two to four times as many cuttings as the desired established population. Mortality of 50 percent is not uncommon during the rooting phase. Another 50 percent of the cuttings may be lost to mortality when the cuttings are outplanted. Cuttings are grouped in bundles, often 25 or 50 cuttings per bundle, to keep track of the total. Bundles should be labeled with the correct plant collection information.

Cuttings can deteriorate rapidly. They must be kept moist, cool, and out of the sun. After the cuttings have been taken out of the field, they should be stored at 34 to 38 degrees Fahrenheit (1 to 3 degrees Celsius). Take care that they do not freeze. Cuttings should be rooted as soon as possible, but some species can be stored for up to several weeks. If cuttings are going to be shipped to a professional grower, ship them early in the week to make sure they arrive before the weekend.

To cut the stem cleanly, use sharp scissor-type, hand-pruning shears. Anvil-type shears will crush the stem. Cut the stems at a 45-degree angle to increase the rooting surface. Recut the upper end of the stem at a 90-degree angle so the upper end can be distinguished from the lower end (figure 3–116).

Cut off side shoots. Save those that are large enough to plant. It is best to collect cuttings in the morning while the stems are fully turgid. Depending on their size, the cuttings can be placed in small wet plastic bags, wet burlap bags inside a plastic bag, or in triple-layer paper bags. To avoid harming a donor plant, do not remove more than 30 percent of the branches from any one plant.

3.10.9b Semihardwood Stem Cuttings

Semihardwood cuttings are taken in late summer or early fall from the partially matured growth of woody plants. Stems are ready if they snap rather than crush when they are bent.

3.10.9.c Hardwood Cuttings

Hardwood cuttings are taken when the plant is dormant in the late fall or winter. Cuttings should not be taken after the buds have begun to swell in late winter. Deciduous plants enter dormancy when the leaves have dropped. Cuttings

Figure 3–116—Cut stems with bypass pruning clippers at a 45-degree angle to increase the rooting surface. Recut the upper end of the stem at a 90-degree angle so that the upper end can be distinguished from the lower. This photo was digitally altered.

should include the terminal bud (figure 3–117), and be 6 to 24 inches (152 to 610 millimeters) long and $^3/_8$ inch (9.5 millimeters) in diameter. Include at least two nodes, with the bottom cut being just below a node. Thick, young stems root best because they have carbohydrate reserves. (Huber and Brooks 1993; Weisberg 1993).

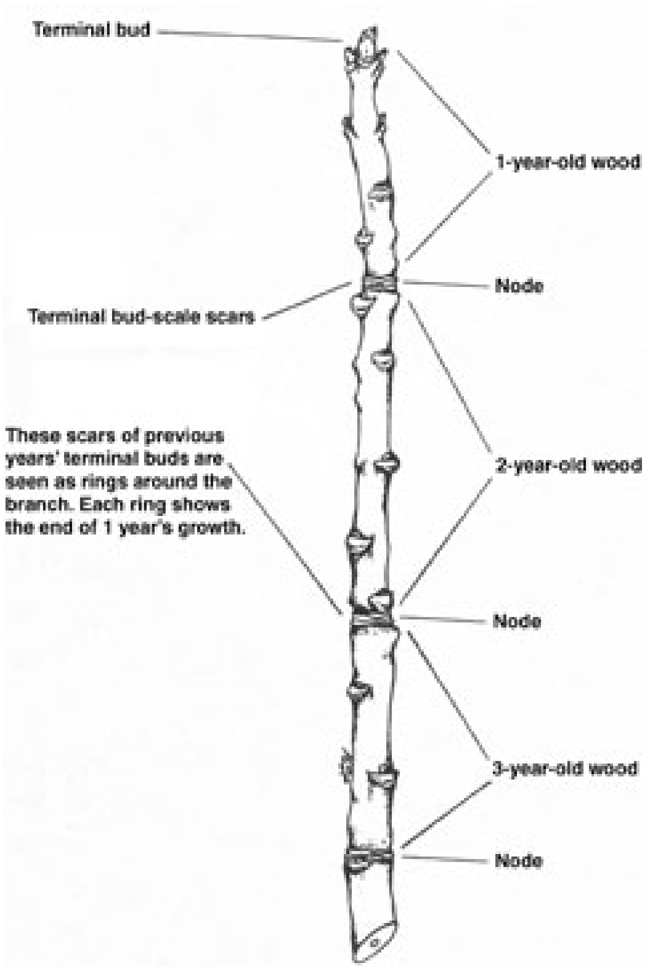


Figure 3–117—Determining the age of a branch. Drawing courtesy of Carol Aubry (Potash and Aubry 1997).

3.10.9d Softwood and Herbaceous Cuttings

These cuttings are taken in spring or early summer from the rapidly growing tip of plants. This type of cutting is subject to wilting.

3.10.9e Root Cuttings

This technique is possible for some species with roots or rhizomes that produce stem buds. Donor plants need to be prepared by closely root pruning them and pruning back the foliage before the growing season (see section 3.10.12, *Transplanting Wildlings*, for this technique). Vigorous new roots that can produce stem buds will form quickly during the growing season. The new portion of the root is the part closest to the crown. Cut the root away at a 90-degree angle (so the upward end remains recognizable), then cut off the thin end with a sloping cut. Remove fibrous lateral roots. The number of plants from each root can be maximized using the following rule of thumb:

- If planting the cuttings directly into the ground, cut the root in 4-inch (100-millimeter) segments.
- If propagating the cuttings in a cold frame or cold greenhouse, cut the root in 2-inch (50-millimeter) segments.
- If planting the cuttings in a heated greenhouse, cut the root in 1-inch (25-millimeter) segments.

Root cuttings are subject to fungal rot. Dust them with sulfur or Captan, an antifungicidal powder. Use 1 teaspoon of Captan for every 100 inches (2.54 meters) of root. Place the roots and powder in a plastic bag and shake. Plant the segments with the crown end up. The crown has the perpendicular cut. It is best to take root cuttings during the dormant season.

Root cuttings have the potential for onsite propagation. Try replanting 4-inch (100-millimeter) or longer root segments immediately while the soil is moist. Do not water the cuttings until shoots appear (Browse 1979). Sprigging is an onsite technique that uses machinery to closely crop vegetation back to the crown before lifting the root systems from the ground. The sprigs are spread over the restoration site, covered with soil, and lightly tamped. This technique works with grass and shrub species that sprout from their roots or are rhizomatous (Redente 1993).

3.10.9f Leaf Cuttings

A few native plants have the ability to produce plantlets on leaves that have just expanded to their full size. Bulb scaling is a form of leaf cutting in which a scale from a bulb is peeled off and planted separately. This method of propagation is tricky. The most common failure is that the leaf rots before it can root. Cuttings need to be processed before the leaves wilt or desiccate.

3.10.9g Leaf-Bud Cuttings

This type of stem cutting can be taken from anywhere on the stem. It is an undamaged mature leaf with a very short piece of stem that has a leaf bud in the axil where the stem and leaf join (figure 3–118). The upper portion of the stem is cut away at an angle just above the bud (Browse 1979).

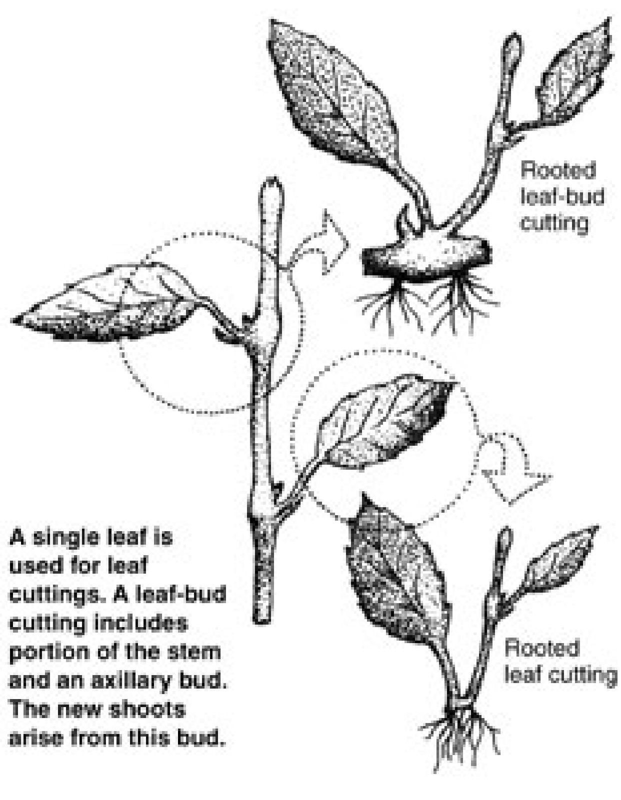


Figure 3–118—Taking a leaf bud cutting. Drawing courtesy of the Washington State University Extension Office (*Propagating Herbaceous Plants From Cuttings*, Pacific Northwest Extension Publications 2001).

3.10.10 Divisions

Divisions are taken from plants where the fibrous root mass or crown lends itself to being split into more than one plant. Each division has both roots and shoots. Divisions can be made easily with strawberries or plugs of grass (figure 3–119). Divisions can be done over and over at a nursery, greatly increasing the amount of plant material gained from a donor plant. Divisions also can be used as an onsite propagation technique. The donor plant is dug from the ground carefully and split with hands or a knife into more than one plant, with each division being replanted. According to Krystyna Urbanska, a Swiss alpine restorationist, alpine grasses can be divided into single tillers, maximizing plant material (Urbanska 1986).

Figure 3–119—Some plants, such as strawberries, are divided easily at the roots.

3.10.11 Layering

In layering, a new plant is rooted while it is still attached to the donor plant. A number of plants reproduce naturally by layering, which is to some degree an adaptation to short growing seasons where a seed crop may not be a reliable way to reproduce. Native plants that layer naturally include juniper, subalpine fir, heather, blackberry, and willow.

This method has more potential for propagation onsite than offsite, because a mature plant donor would need to be grown or established in a nursery. Layering works well to restore closed trails if shrubs are growing alongside the trail.

3.10.11a Simple Layering

With this method, a new plant is rooted from a single branch by burying the branch about 1 foot (about 300 millimeters) back from the tip. This should be done at the beginning of or during the growing season, so roots will begin to form immediately. Prevent the soil from drying too much while the branch is rooting. The newly rooted plant can be cut away from the donor plant at the end of the growing season or during the following spring if the plant was layered during the midseason. Check for roots before cutting the new plant away from the donor. Because the branches are still attached to the donors, your survival rate may look impressive, but it won't be if roots have not formed.

The first technique for simple layering is to dig a 6-inch- (150-millimeter-) deep hole at the correct spacing away from the donor plant, ideally in the site to be restored. The branch is bent into a "U" shape over the hole, about 1 foot (about 300 millimeters) back from the tip (figure 3–120). Leaves are removed from the portion of the branch to be buried. Rooting is stimulated by partially breaking the branch, abrading the bark with a pocket knife, or by twisting or girdling the shoot between the "U" and the donor plant. If necessary, the stem can be anchored to the bottom of the hole with a peg or rock.

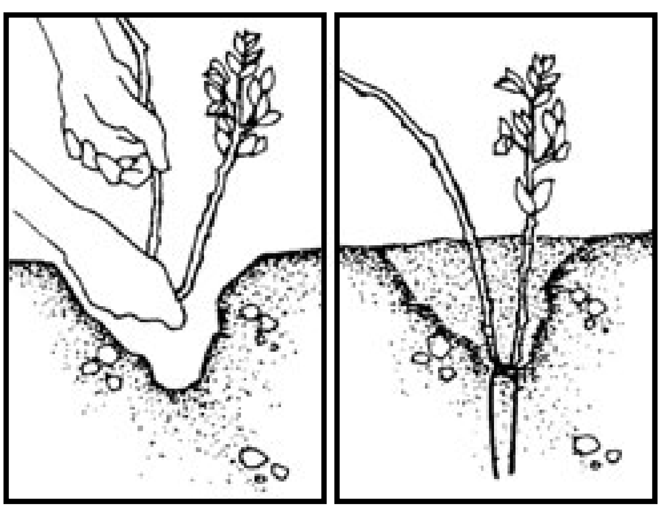


Figure 3–120—These drawings show simple layering. Drawings courtesy of Jenny Tempest (Hanbey 1992). The plant's stem is abraded or girdled to stimulate root production before the stem is pinned underground.

Firmly pack the hole with soil. You may want to stake the branch to keep it upright.

The second technique for simple layering is used on plants with branches that are low. The branch is covered with 3 to 4 inches (76 to 101 millimeters) of soil, 12 inches (about 300 millimeters) back from the tip (Weisberg 1993). Once roots have formed, the stem from the parent plant can be cut and the new plant can be moved.

3.10.11b Mound Layering

The concept behind mound layering is to root many new plants from the same shrub (figure 3–121) by forcing each branch to develop roots. This technique works well with shorter shrubs or stiffly branched plants. The shrub does not need to be immediately adjacent to the restoration site. Mound layering is begun just before the growing season begins, and plants are cut from the donor in the spring or following fall.

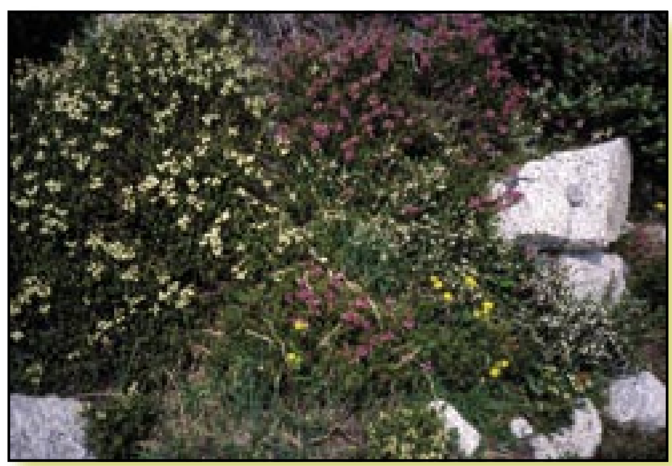


Figure 3–121—Heather can be propagated with mound layering (Weisberg 1993). This technique holds promise for a species that is challenging to propagate.

Select a mature shrub and prune each branch back to 3 inches (76 millimeters). Once new shoots are 3 to 4 inches (76 to 101 millimeters) long, soil is mounded over the crown of the plant (similar to hilling potatoes), leaving 2 inches (50 millimeters) of shoot tips above the soil. With species that are more difficult to root, the entire crown is covered with soil ½ inch (13 millimeters) above the branch tips as soon as the branches are pruned. Continue to mound soil several times throughout the growing season to a total depth of 8 to 10 inches (200 to 250 millimeters), leave several inches of the growing tip above the soil. The soil must be well drained and kept moist.

If the new plants are cut away in the fall, the donor plant should be protected with soil for the winter. The same donor plant can be used for several years in a row (Weisberg 1993).

3.10.11c Tip Layering

Tip layering works with a few species, such as blackberries. The concept of tip layering is that the attached shoot tip is buried upside down in the ground, where the terminal bud will turn to push right-side up through the soil.

The growing tip of the side shoots are cut back early in the growing season. By the middle of the growing season, new shoots with small, curled tips will have formed. These tips are bent to the ground, and buried firmly, tip down in a 4- to 6-inch- (100- to 150-millimeter-) deep hole. The soil must be kept moist until fall, by which time a well-developed root system should have formed. At this point, the new plant can be cut 6 to 8 inches (150 to 200 millimeters) above the soil, separating it from the donor plant. The new plant can be transplanted immediately or during the following spring.

3.10.12 Transplanting Wildlings

A wildling is an indigenous plant growing in its native habitat. You may also hear wilderness folk referring to wildlings as transplants or plugs. This guide avoids calling wildlings plugs because we also transplant greenhouse-grown plugs.

Some species can be transplanted successfully as wildlings. This procedure should be used only if adequate plant material exists and care is taken not to cause too much damage to the collection site. If plants can be salvaged from a ground-disturbing project nearby, transplanting wildlings can be relatively inexpensive and effective, especially if volunteer labor is available.

Transplanting wildlings tends to provide vertical relief to a site more quickly than other methods, and there is no risk of introducing nonnative organisms such as weeds, insects, or pathogens. In some environments wildlings establish and spread quickly. Plants that spread underground or with stolons perform exceptionally well. However, on dry, compacted sites, the rate of spread can be slow to nonexistent. Taprooted plants do not transplant well; most are difficult to transplant as wildlings and require special care so that as much root is left on the transplants as possible (figure 3–122). Some taprooted plants are best propagated offsite, where they can be grown in tall pots. Plants having long, brittle, horizontal roots, such as heather or vine maple, also are difficult to transplant. Such plants probably should only be transplanted if they are being salvaged and the plants will be destroyed anyway.

Figure 3–122—Be sure to have pruning clippers or a root saw handy if you salvage wild plants that have taproots. Drawing courtesy of Jenny Tempest (Hanbey 1992).

Wildlings should be transplanted in their new location as quickly as possible. Some delay may be unavoidable if restoration follows a salvage operation. Dig the holes at the restoration site before digging out the transplants. Holes need to be refilled after transplants are removed.

Larger plants, such as small trees, tend to be difficult to transplant successfully. Their root-to-shoot ratio is not high enough to allow them to survive transplant shock. Large plants can be prepared for transplanting by root pruning, a common technique in the nursery and landscape industry that increases the root mass dramatically. A sharp shovel is inserted into the ground, making a vertical cut through the roots all the way around the outer perimeter of the plant's foliage, known as the drip line (figure 3–123).

Figure 3–123—Roots are pruned two or more times to stimulate root production before transplanting. The roots are pruned by sinking a shovel blade vertically into the soil around the drip line of the plant that will be transplanted. Drawing courtesy of Jenny Tempest (Hanbey 1992).

A tree spade is the tool of choice, because it has a relatively flat blade. A scoop shovel can work if care is taken to keep the blade perpendicular to the plant. Root pruning needs to begin early in the growing season of the year the tree will be transplanted, or even the year before, with several cuts made throughout the growing season. Not only will survival rates be higher after root pruning, but the tree will be easier to lift for transplanting as well. Root-pruned plants need to be tagged to facilitate relocation.

Wildlings should be transplanted in the spring or fall, or better, when the plant is fully dormant. Otherwise, transplant shock is likely.

If possible, wildlings are watered the day before they are lifted from the collection site. Transplanting should take place during the morning or on a cloudy, cool day while the plant is fully turgid. The digging technique is similar to root pruning. The shovel cuts are made into the soil around the plant with the blade as nearly perpendicular to the surface of the ground as possible. It is important to have a good ball of soil around the wildling's roots, and to dig out as much of the root system as possible.

Pay attention to root morphology. On well-developed soils or on arid lands, roots will grow down more than out. On shallow soils or on areas with permafrost, roots will spread out, making it necessary to dig up a much larger area around the plant. In general, larger plugs have a better chance of survival than small plugs. For relatively small plants, such as graminoids or forbs, a good rule of thumb would be to have the plug about as wide as a scoop shovel, and about 8 inches (200 millimeters) deep. Experimenting with various plug sizes is a worthy endeavor. If all plugs survived, smaller plugs would allow more transplants.

Some shrub and tree species transplant more successfully if their north-to-south orientation is maintained. Mark the orientation in some way, such as by hanging a flag from the north side of the plant.

Use the shovel and your hands to lift the root ball gently out of the hole, keeping the root ball together. Hand pruners can be used to cut away woody roots that do not come free with the shovel. The root ball can be transferred into a 5-gallon (19-liter) bucket, a wheelbarrow, or plastic or burlap bags for transport to the restoration site. If wildlings are dug from sandy soil, the soil will fall away from the roots. Use buckets of water, wet rags, or jelly roll material to protect the roots until the wildling can be transplanted. Denali National Park uses heavy equipment to salvage large, shallow pieces of sod (up to the size of a bucket on a front-end loader). If the use of machinery is not an option, smaller pieces of sod can be cut and moved by several people (Densmore and Vander Meer 1998).

3.11 Transplanting, Protecting, and Establishing Native Plantings

Proper transport and transplanting procedures are critical to the survival of transplants. In addition, all plants must be given adequate water, mulch, shade, protection from animals that might eat them, and so forth.

3.11.1 Timing of Transplanting

The timing of transplanting will vary depending on the species, the environment, and the ability to provide initial care, such as irrigation, for transplants. In general, transplants need time to become established before being subjected to potentially lethal environmental extremes. In most environments, transplanting takes place during the spring or fall while the plants are dormant, just emerging from dormancy, or preparing for dormancy. Transplanting in winter is possible in environments where the ground is not snow covered or frozen. Although transplanting during the summer should not be ruled out completely, doing so risks subjecting plants to drying winds, too much heat, and inadequate moisture. The roots of some species grow only when they have adequate soil moisture.

For arid lands, most practitioners advocate fall or early winter plantings (figure 3–124). Desert plants have warm- or cool-season growth patterns. Cool-season species are best planted in the fall, while warm-season species, such as blackbrush (*Coleogyne ramosissima*), may transplant better with a spring planting. Planting in hot deserts is often done during winter (Belnap and Furman 1997). According to some practitioners, timing is not as critical as one might expect. Midsummer plantings of mesquite (*Prosopsis glandulosa*) have had high survival rates, but other species such as palo verde (*Cercidium floridum*), were more sensitive to drying wind and high heat (Bainbridge and others 1992).

Figure 3–124—For arid sites, fall or early winter plantings are the most likely to be successful.

In subalpine environments, transplanting generally occurs in September and into October (figure 3–125) when soils are moist (minimizing the need for additional watering after planting) and plants are slowing their metabolism before

Figure 3–125—In subalpine areas, planting is done in September and October just before the winter snowfall.

entering a dormant phase. It is possible to transplant just after the snow has receded in the early summer, or by late August, but the survival rate of plantings will be lower. Irrigation is likely to be needed throughout the remainder of the growing season.

And finally, plants should be transplanted before they seed. Otherwise, seed will be churned in too deeply or fragile seedlings will be damaged.

3.11.2 Transporting Nursery-Grown Plants to the Project Location

Nursery-grown plants may have their foliage or roots desiccated, their foliage crushed, or their stems broken when they are transported to the restoration site. The method of transport also can have an impact on the physical landscape or soil. For example, using a helicopter to transport plants quickly and with no disturbance to soil and vegetation may be a good option, but this practice conflicts with wilderness values. Even though mules or llamas (figure 3–126) may cause noticeable soil disturbance when they are used to transport plants to a fragile location, this disturbance may be less than the disturbance caused by the feet of the many workers needed to accomplish the same task.

Figure 3–126—Llamas or mules work well for transporting plant materials to most work sites. It's best to get the packstock in and out quickly so the animals don't damage your project site.

Plants should not be brought into the project area before transplanting is scheduled. This is especially important in arid environments, where shade and water are scarce. In a more temperate environment, plants can be held over for short periods by storing them in the shade and watering them as needed.

A number of methods have been developed for packing and transporting plants. It is critical to protect plants from exposure to air, heat, cold, or sunlight. Containerized plants should be watered before being transported. If weight is an issue, plants may be transported for a brief time with partially moist soil. Weed seedlings or moss growing on the potting medium should be removed before transport. If heat is a concern, some ventilation needs to be provided, while the plants also need to be protected from wind. Light-colored canvas tarps work better than plastic tarps because the canvas allows for some ventilation, reducing the risk of overheating.

3.11.2a Jelly Rolls for Protecting Bareroot Stock

When bareroot seedlings are lifted out of their growing medium, they can be dipped in a slurry of water and vermiculite and placed on damp fabric. The fabric is rolled as more plants are added. The rolls are placed in plastic bags and kept cool (39 degrees Fahrenheit, 3.9 degrees Celsius) in a controlled environment or by placing them on ice. Dry ice should not be used, because it is too cold and is toxic to plants. In addition to keeping roots moist, jelly rolls reduce the weight of the materials needed to transport seedlings and the space required to do so. For example, 98 plants in a sand-filled rack of supercells weigh about 50 pounds (22.7 kilograms), compared to 30 pounds (13.6 kilograms) for an ice chest holding 300 plants in jelly rolls packed on ice (Bainbridge and others 1992). Plants can be rolled in wet burlap, but reusable toweling works best for jelly rolls. For additional information on jelly rolls and reusable toweling, refer to *Reusable Toweling for Wrapping Tree Seedlings*, available at *http://www.fs.fed.us/t-d/pubs/htmlpubs/htm05242323/* (Username: t-d Password: t-d).

3.11.2b Moving Plants In Containers

Plants that are in containers need to be placed in a relatively rigid device with enough packing material between pots or flats to prevent them from being damaged by jostling during transport. If packstock are used to carry the plants, plan for "rodeos"—try to pack the plants so they will not be damaged if loads are thrown topsy-turvy. Containers help protect the roots from desiccation during transport and make it easier to hold and move plants at the project location. Disadvantages include the larger volume of containers that will need to be carried in and out.

Tree-planting boxes are large, sturdy waxed-cardboard boxes in which the Forest Service receives shipments of tree seedlings. These boxes, usually discarded after planting, are the perfect size for stacking rectangular flats of plants in small containers (figure 3–127). Stacking works well for plants that can withstand moderate crushing, such as graminoids, or plants with rhizomes or stolons. Small spacers can be added across the corners of the flats to reduce crushing. The boxes fit one to a side in canvas panniers or manties for transport on packstock and can be flattened for packing out.

For plants that cannot withstand the abuse of being stacked, find shallow boxes that will hold one layer of containers. Many office supply stores or shipping businesses sell a variety of boxes and are likely to have some that meet your needs. Racks can be devised for transporting plants in cells.

3.11.2c Moving Container-Grown Plants Without the Container

In general, it is best to move the plant in its container because the container will protect fragile roots. Some species, such as grasses and sedges, have well-developed root systems that can withstand the abuse of being removed from pots for transport. The soil around the plants should be moist to protect roots from desiccation.

Package plants by removing them from their pot and placing them in layers in large plastic bags lining larger containers, such as 5-gallon (19-liter) buckets (figure 3–128), boxes, or stock panniers. A sheet of newspaper between each layer of plants may help keep the seedlings separated.

Figure 3–127—Discarded Forest Service tree-planting boxes are the perfect size for loading flats of plants. Spacers can be used between flats to prevent crushing delicate species. Packing material can be added to take up excess room. These boxes fit in panniers, so they can be used with packstock.

Figure 3–128—Sturdy plants, such as sedges, can be removed from their pots and transported directly in buckets or boxes to save space.

3.11.2d Protecting Fragile Foliage

Plants with fragile stems, such as lupine, are difficult to transport. The fragility may influence the type of transport; packstock may not be appropriate. Cylinders can be made around the plants. For instance, each plant could be rolled securely in newspaper and packed so they remain upright. Use enough packing material to keep the plants from shifting.

3.11.2e Moving Plants With Helicopters or Other Vehicles

Plants can be packaged for planting using any of the methods described above. During transport, the plants need protection from wind. A canvas tarp can be used to cover loads that would be exposed otherwise.

3.11.2f Handling Plants After They Arrive at the Project Location

Upon arrival, plants should be watered and stored in the shade. If no shade if available, a shelter can be constructed from a canvas tarp or shade cloth. Most subalpine species can be placed in shallow water for short-term storage, such as in a pond, a shallow pool or a creek, or even in toddler wading pools set up in the shade. Branches or leaves that were damaged during transport should be cut back.

3.11.3 Transplanting Techniques

The same method is used for planting wildlings as for nursery stock. Good transplanting technique will improve the survival rates significantly. Common mistakes include planting seedlings too shallow, too deep, or too loosely; orienting wildlings incorrectly; damaging roots by exposing them to air; or failing to place root stems properly. With transplanting, the quality of the work needs to be monitored and supervised carefully. Quality—not production rate—should be given first priority.

Ideally, the spacing of plants is specified. For a natural appearance, plantings should be grouped in irregular patterns. The planters should observe the natural distribution and spacing of each species and try to emulate that pattern. When plants are not available at the correct ratios for such a pattern, planters must use their best judgment to mimic the native stand. If seedlings are planted too densely, they may need to be thinned or moved as they mature. It may be wise to plant a few more seedlings than desired to compensate for mortality.

Ideally, seedlings should be planted on a cool, cloudy day or while the restoration site is in shade. Experience will determine how important these recommendations are for your project. Water the seedlings before planting them. Dig the planting holes before exposing the seedlings' roots to the air. Planting holes should not be allowed to stand empty for too long, because the exposed soil will dry out rapidly. When possible, planters should take advantage of microsites, such as rocks, logs, or depressions, to give the seedlings a bit more protection from sun or wind (figure 3–129).

Figure 3–129—Planting seedlings against a log or rock helps protect them and provides them additional water. This photo was digitally altered.

A variety of tools, including shovels, hoedads, and dibbles, can be used to dig planting holes. For small containerized stock, small hand-held pick hoes (figure 3–130) are the most efficient planting tools. In areas where soils are deeply compacted, a rock bar or soil auger may be needed to dig planting holes. Power augers may be the minimum tool for digging holes on especially difficult soils, such as caliche. In clayey soils, augers may leave a smooth glaze on the soil that is difficult for roots to penetrate; this glaze can be prevented by using specialized auger attachments.

Figure 3–130—Trowels are not the tool of choice for planting. A hand-held pick hoe (shown) or plow share works well for planting smaller plants. A shovel is needed when planting larger plants.

The planting hole is dug about one-third larger than the root system of the transplant. The soil should be loose on the sides and bottom of the hole. Water the planting hole with enough water to saturate the soil. Trim damaged roots off transplants, and gently tease roots apart if containerized plants are rootbound.

When placing the plant in the hole, maintain the natural alignment of the roots. Be sure that the roots are not doubled back. Taprooted plants, such as tree seedlings, will die if their roots are doubled back because the root system cannot correct its orientation to reach water in the deeper soil layers. If transplants have fibrous root systems, it sometimes helps to build a mound in the bottom of the hole and spread the roots out around this mound.

The crown of the plant should be at or slightly below ground level; some species will die if the crown of the plant is buried. A slight depression will catch water and afford a measure of protection from the elements. Another way of catching water is to build up a rim of soil around the transplant. The hole is backfilled, tamping the soil firmly without crushing plant material, and watered layer by layer (figure 3–131). Make sure to spread roots in the hole. Finally, planters should use the weight of their forearms or feet to snug soil down, removing air pockets from the soil around the transplant's roots.

Figure 3–131—Once a transplant is placed in a hole, soil is packed firmly around it to eliminate large air spaces. Gently stepping around the transplant helps snug it in. A shallow depression around the transplant will help retain water.

Tamping also helps prevent frost heave. Shallow plugs of sod may need to be anchored with pegs so they maintain firm soil contact. At Denali National Park, restorationists use U-shaped pins made from rebar to anchor shallow-rooted trees. The pins help keep the trees from toppling over (Densmore and Vander Meer 1998).

The quality of the transplanting job can be monitored by tugging gently at each seedling. If a plant pulls loose, it needs to be replanted more securely. The planters should monitor their own work, and a supervisor should conduct spot checks for quality control.

When planting seedlings among living roots, plant between the roots as much as possible. In some cases, such as with huckleberry, roots resprout once growing conditions are favorable. Ruth Scott has found the opposite to be true at Olympic National Park; sites where root systems were minimally disturbed during planting were slow to recover. Better overall results were obtained by thoroughly scarifying the soil before replanting (Scott 2002).

Plants have tiny root hairs that are destroyed almost immediately when they are exposed to air. These root hairs represent a large percentage of the total surface area of the root system. It is crucial to avoid exposing the root hairs to the air. At Joshua Tree National Park in the Southwest, the tall pots used to grow seedlings with long roots have a screen on the bottom. When the seedling is planted, the screen is removed and the entire plant—including the pot—is lowered into the planting hole. While a stout dowel is used to push the plant down, the pot is removed slowly as soil and water are added into the hole around the roots. Holes drilled near the rim of the pots allow hay hooks to be used to lift the pot away from the plant. This technique protects the delicate root systems (figures 3–132a and 132b).

Figures 3–132a and 132b—Roots can be kept moist when seedlings are grown and planted in PVC pots with removable screen bottoms. Once the pot and seedling have been planted (top), the pot can be removed (bottom), as shown here at Joshua Tree National Park, CA.

Transplants should be watered as soon as they have been planted. Wildlings should be pruned back by one-half to one-third of their original size if the plant's morphology allows pruning. If transplant shock is anticipated, an antidesiccant spray can be applied to the foliage. Mount Rainier and Denali National Parks water their transplants with Vitamin B1 to prevent transplant shock (Densmore and Vander Meer 1998; Rochefort 1990). Vitamin B1 is available from nursery suppliers or garden supply stores.

If soils at the restoration site are altered significantly, the site could be inoculated with mycorrhizal fungi or nodules containing nitrogen-fixing bacteria by spreading a thin layer of inoculum in the planting hole. The methods for doing so are described in section 3.2.5b, *Inoculating Plants With Mycorrhizal Fungi*.

Consider situating some plantings against rocks or logs. The rock provides additional protection and additional water, especially if a long, sloped surface directs water to the plant.

Some irrigation devices, such as deep pipes or clay pots, are installed as part of the planting process. Mulch, shade cards, signs, and devices to reduce wildlife damage generally are installed immediately after planting. These techniques are described in section 3.12, *Plant Protection and Establishment*.

Transplanting Checklist

- Protect plants during transport and at the work site.
- Select a staging area with resilient vegetation where supplies can be stored and workers can take breaks.
- Dig and water planting holes.
- Expose the seedlings' roots to air only when they are ready to be planted.
- Inoculate seedlings with mycorrhizal fungi or nitrogen-fixing bacteria, if needed.
- Orient wildlings correctly (the side of the wildling that faced north before transplanting should face north afterward).
- Position the seedlings' roots naturally when filling the hole.
- Gently tamp in layers of soil around the roots to remove air pockets.
- Water each layer of soil, and water again when done planting.
- Check that each small transplant is planted securely by gently tugging it upward; replant, if necessary.
- As appropriate, protect the plant with mulch, devices to reduce wildlife damage, shade cards, or signs.
- Clean up the work area daily to minimize damage.

3.11.4 Salvaged Materials

Ideally, transplants should be planted as quickly as possible. Plants can be held for a short period of time in the shade or shallow water (figures 3–133a and 133b).

Figures 3–133a and 133b—For a short time, salvaged plant materials can be stored in shallow water (top) or in the shade (bottom).

Sometimes, salvaged materials cannot be planted quickly because they need to be removed long before the area is ready. The plants may have to be held for an extended period.

In general, holding beds, similar to a garden, are used for the salvaged plants. Plants are provided with irrigation and shade, as needed. You may need to prune back the crowns of the plants to improve the root-to-shoot ratio. If you plan to salvage plants, check with local restorationists to learn the methods that work best for your species. Plants may require additional protection, such as a thick layer of mulch or sawdust, if they are held over winter.

3.12 Plant Protection and Establishment

This section explains additional cultural techniques for protecting and establishing vegetation. These techniques, including mulching, irrigation, and devices to protect plants from wildlife damage, often are critical to the success of restoration projects.

3.12.1 Mulching

Mulch is material placed on the soil surface or around transplants to prevent erosion and to protect plants from heat, cold, and drought. Mulch includes loose materials such as straw, native hay, rock, or wood chips and products made into mats from a variety of materials (figure 3–134). Mulches must be installed securely in close contact with the soil to work well. Vertical mulches are installed upright to cast shade and to protect plants from the wind.

Figure 3–134—When it's time to roll out the carpet (the erosion-control blanket in this case), there is a great sense of satisfaction, nigh unto gaiety. The hard work to prepare and plant a site is almost done!

3.12.1a Advantages and Disadvantages of Mulching

The advantages of mulching include:

- Reducing erosion substantially by deflecting the impact of raindrops, reducing the velocity of moving water, and serving as miniature checkdams to hold soil in place.
- Increasing soil moisture by reducing evaporation and increasing water infiltration.
- Protecting germinants and plants from too much heat in the summer by reducing soil temperatures.
- Protecting plants from frost heave and needle ice in the fall by maintaining warmer soil temperatures.
- Providing some organic material for soil building.
- Protecting plants from wind.
- Preventing soil from crusting and recompacting.
- Improving soil structure, allowing soil microorganisms to recolonize.
- Protecting plants from solar radiation.
- Preventing weed establishment if the layer of mulch is thick (but also preventing native seed from germinating).
- Preventing birds from eating seed.
- Trapping seed on the site.
- Demonstrating to visitors that "Something is happening here."

Because of these benefits, mulching can increase germination rates, seedling survival, and plant growth. For example, Mount Rainier National Park compared germination and establishment of native species in the subalpine zone using a variety of mulches. Their findings (table 3–14) show the relative benefits of using mulch.

Table 3–14—Seeding success after 1 year, comparing different mulch materials in the subalpine zone at Mount Rainier National Park (Rochefort 1990).

Mulch	Seedlings per square yard (per square meter)
Straw blanket	451 (377)
Curlex	292 (244)
Rollite	258 (216)
Native sedge	87 (73)
No mulch	48 (40)

In some cases, mulching makes no difference in success. Mulch may actually be detrimental, depending on the type of mulch. Mulching also increases the project's cost.

The disadvantages of mulch include:

- Keeping some soils too cool in spring, such as those in alpine fellfields. Thinner mulch or a darker mulch will help raise spring soil temperatures.
- Inducing premature germination without adequate water to support the germinant. Covering seeds with soil will prevent this problem.
- Decreasing establishment of some species. For example, in a native bunchgrass community, a 50-percent cover of native grass mulch suppressed seedling establishment (Belnap and Sharpe 1995).
- Increasing susceptibility to fire, because some mulch materials, such as jute and straw, are highly flammable (a spray application of monoammonium phosphate fertilizer will serve as a fire retardant).
- Creating cover that allows rodents and insects to eat seed without being exposed to predators.
- Reducing soil nitrogen levels because of decomposition if organic mulch materials are mixed in with the soil.
- Increasing weed problems, because straw mulch can have both grain seed and other weed seed mixed in. Even certified weed-free straw can have a small percentage of noxious weed seed and any amount of other weed seed. Rice straw is a good alternative because rice will not grow on dry soil, nor will the aquatic weeds associated with rice grow on dry soil.
- Preventing moisture from reaching the soil in areas with very light rainfall.
- Preventing native seed that drops on top of mulch mats from establishing when it germinates.
- Persisting in some environments because mulches can degrade slowly in certain conditions.
- Trapping animals in the net that covers some mulches.
- Slowing seed germination and seedling growth in the subarctic.

3.12.1b Selecting a Mulch

Mulch should be selected to mimic the structure and function provided by the natural litter layer. For example, a meadow normally would have dead leaf material that serves as a mulch. That material not only would regulate soil temperature and soil moisture, but would add nutrients to the soil as it decomposes. A straw or natural fiber mulch would mimic this condition. In a desert or alpine fellfield with little leaf litter, rock tends to serve as mulch.

The type of mulch selected and the application rate will depend on conditions at the site, such as slope, erodibility, soil temperatures, moisture, wind, the potential for weed infestations, and the potential that wild animals might cause damage. Cost will be a factor, but because of the labor-intensive nature of work at roadless locations, the cost of mulch is often insignificant. As with the other aspects of project planning, it is a good idea to consult with other practitioners who have worked in similar environments or with the same species of plants to learn the mulches that are the most effective. Be open to experimentation; studies of mulching in similar environments have yielded seemingly contradictory results.

3.12.1c Comparison of Different Types of Mulch

Mulches used at remote roadless sites are composed of native materials or of materials that will degrade naturally. They can be installed without motorized tools. A number of nondegradable mulch materials are used extensively in reclamation projects outside wilderness, but because of their long-lasting unnatural appearance and because they are less effective in controlling erosion, these materials will not be discussed (Harding 1990; Theisen 1992). Hydromulching, which requires a truck-mounted sprayer system, also will not be covered here, but is a common mulch used for road projects along roads in temperate areas.

Native Hay or Leaf Litter

When an area has enough grass and forbs, native hay can be cut with a sickle (figure 3–135) or a scythe or raked up with a thatching rake. Native hay provides an additional source of seed. Leaf litter can be collected from adjacent areas, taking care to not collect too much in one area. Because native hay shrinks as it dries, it takes a lot of hay to provide an adequate mulch layer. Native hay or leaf litter will wash or blow away unless it is crimped into the soil with a shovel, or anchored with a tackifier, photodegradable nylon net, or jute. Collecting native hay or leaf litter takes a lot of time, so plan for increased labor.

Native Rock

Although it may seem improbable, rock can make an excellent mulch with a natural appearance. If the project site would have been rocky before disturbance, consider using rock as a mulch and to improve the area's appearance (figure 3–136). Rock will provide sheltered microhabitats where

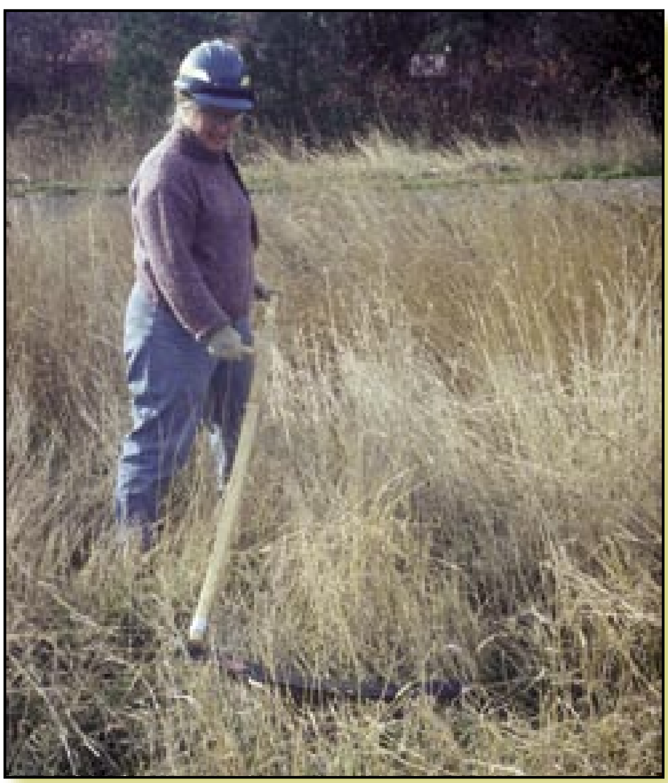


Figure 3–135—Native hay can be collected with a sickle or scythe. Here, coauthor Lisa Therrell is harvesting native hay in Chelan County, WA.

Figure 3–136—Rock snugged up to these alpine cushion plants provides effective mulch at St. Mary's Peak in the Selway-Bitterroot Wilderness, MT.

plants can reestablish. Larger rocks provide shade and may funnel rainfall to plants. Some projects have used gravel up to an inch thick as imported mulch. This technique is especially important in arid lands (Bainbridge and Virginia 1990) and in sparsely vegetated alpine environments, such as fellfields (Rochefort 1990). Rock also can be incorporated with other mulches. If you are collecting local rock, avoid overcollecting from any one spot. If you are importing gravel, make sure that the source is free of weed seed or have the gravel cleaned before using it (monitor the site for weeds after planting).

Straw

Loose straw is the most common mulch used on large-scale restoration projects because it is effective, inexpensive, and easy to apply with machinery. The longer the stem, the more effective straw is as mulch. Seedling establishment has been high on many projects that used straw mulch. On slopes or windy areas, straw must be crimped into the soil or anchored in the same ways as native hay. Straw decomposes within 1 to 3 years. It may not be the best choice for a site that needs long-term protection.

Usually, about 2 tons of straw is applied per acre (0.09 metric ton per hectare), providing about 66- to 100-percent cover that is about 2 inches (50 millimeters) deep. Applications vary from 1 to 8 tons per acre (0.45 to 3.56 metric tons per hectare) when straw is crimped into the soil (refer to section 3.4.8c, *Crimping*). For seedlings to germinate and become established, soil needs to show through the straw. A heavier application of straw will help suppress weeds and keep the soil cooler. If the introduction of weedy species is a concern, rice straw is best. It is a byproduct of rice grown in California.

Bark or Wood Chips

Bark or wood chips work well as mulch on arid lands where the high carbon-to-nitrogen ratio (expressed as carbon: nitrogen) minimizes undesirable nutrient inputs into the soil (Bainbridge and others 1995). On projects that require higher fertility, the carbon:nitrogen ratio of bark or wood chips could be a problem. Richard Miller, Forest Service soil scientist, suggests that for a 1- to 2-inch- (25- to 50-millimeter-) thick layer of wood mulch, 50 to 100 pounds (23 to 45 kilograms) of nitrogen fertilizer should be applied. If the nitrogen is in the form of urea, twice that amount would need to be applied during rainy weather to prevent losses to volatilization (Potash and Aubry 1997). Wood chips may blow away or be washed downhill by surface water.

Jute Netting

Jute is made from a heavy hemp fiber woven into an open net (figures 3–137a and 137b). Jute is easy to apply and is less expensive than erosion-control blankets. Jute only

Figures 3–137a and 137b—Ten years of exposure to sun and weather in the subalpine zone of Washington has not decomposed this jute netting (top). Jute (bottom) is no longer used in such settings.

provides moderate erosion control, so it is less effective in areas with runoff. Because of its open weave, it does not provide the benefits of mulch, but it does allow natural seeding to occur. Jute is highly flammable.

Erosion-Control Blankets

Erosion-control blankets are generally a layer of straw, wood shavings, coconut fiber, or paper stitched through to hold the mulch in place, or sandwiched between layers of net, before being compressed into a roll. Some product lines combine mulch materials, such as straw, with wood shavings. Except for the straw products, erosion-control blankets should protect plants without adding weed seed to the site. Erosion-control blankets are the most expensive type of mulch, but their cost may be insignificant, given the total project costs at some wilderness and remote sites. Numerous companies make the erosion-control blankets described below. See chapter 5, *Tools of the Trade and Other Resources*, for a detailed comparison of various biodegradable erosion-control blankets, as well as sources where they can be purchased.

The advantage of erosion-control blankets over loose mulch materials is that the blankets can be anchored easily to prevent them from blowing or washing away. Blankets are installed according to the manufacturer's instructions, overlapping their edges by about 4 inches (100 millimeters), and using metal pins to hold the matting down. Rocks or limbs also can be used to help anchor the blanket and break up the blanket's unnatural appearance. If blankets are not installed properly, they can injure seedlings. A chain saw can be used to cut a roll into narrower widths. For example, sometimes half the width of a 4-foot (1.2-meter) roll is just right for mulching a closed trail.

Types of Erosion-Control Blankets

Excelsior Blankets—Excelsior blankets (figures 3–138a and 138b) made from aspen shavings have been used extensively on subalpine restoration projects. Excelsior blankets hold in soil moisture and have been advocated for dry sites, such as exposed ridges. The unnaturally bright color of the wood shavings can be alarming when the blanket is first unfurled, but the blanket turns gray after a season or two of sun, rain, and snow. In subalpine environments, the wood fibers last just a few years; a second application may be needed to continue protecting the site.

Figure 3–138a and 138b—Erosion-control blankets made of excelsior (aspen shavings) are alarmingly bright when they are first rolled out (top). After 1 year, they begin turning gray (bottom).

Coconut-Fiber Mats—Coconut-fiber mats (figures 3–139a and 139b) have a natural-appearing brown color and have been used successfully in a number of environments. At Denali National Park, coconut mats are lifted gently as soon as the dicotyledon species, such as legumes, have germinated. The mat is reused (Densmore and Vander Meer 1998).

Figures 3–139a and 139b—Coconut Man sports a wig showing off the dark brown color of a freshly unfurled coconut fiber erosion-control blanket (top). At this subalpine site, the coconut matting had begun deteriorating (bottom) 4 years later.

Rollite—Rollite, a brown paper mulch, has been used successfully on alpine sites. Its dark color absorbs radiant heat. Because the blanket is thin, the soil beneath it can warm. The stitching on this product does not readily decompose. This product no longer appears to be on the market, but it is mentioned here to acknowledge the value of a thin paper product for alpine sites.

Single Portable Mats—Single portable mats have been developed for tree seedlings. These mats could benefit seedlings on a site that does not need erosion-control measures. Black plastic mats suppress vegetative competition, but other biodegradable mats have been developed as well (Windell and Haywood 1996).

Vertical Mulch

Vertical mulch is upright mulch, placed southwest of the plant to block the most intense sunlight or in another location to block the prevailing wind. Vertical mulch also provides a place for seed to lodge, funnels rainfall toward its base, and offers protection from trampling or from grazing wildlife (Bainbridge 1996). Vertical mulch can be rock, dead branches, logs, or tufts of straw. Even salvaged plants that die when they have been transplanted continue to serve as vertical mulch (Patterson 1997). Shade cards could be considered a form of vertical mulch.

A Note About Photodegradable Nets

Polypropylene nets can be manufactured with varying amounts of ultraviolet light inhibitors, allowing them to decompose at differing rates. Nets generally break down within 1 to 5 years. More time is needed for decomposition of the little pieces of polypropylene where the cells join. Pieces remaining on the soil are decomposed by soil micro-organisms that convert them to carbon dioxide and water. A number of projects have reported problems with birds, snakes, or rodents getting tangled in the nets and dying. In other areas, this has not been a problem. If animals frequent the project location, this type of net should be avoided or removed after it has served its purpose. Some practitioners remove the net by the second year, after snow and rain have compressed the mulch and made it more stable. Before buying a product with stitching or a net, ask whether the net will degrade. In some cases, the net will be permanent.

3.12.2 Irrigation

Some projects will not require additional irrigation after seeds have been sown or seedlings have been transplanted. The need for irrigation can be determined based on projects that have been successful, or unsuccessful, with the same plant species in similar environments. Many projects water plantings periodically during the dry portions of the first growing season to help seedlings become better established. Most practitioners advocate tapering off watering as soon as root systems are established so plants adjust to their environment.

If irrigation is not feasible, plant species may be selected based on their drought hardiness. Landscape-scale reclamation treatments, such as mine reclamation or reforestation, eliminate the need for supplemental water by planting inoculated locally-adapted species with an adequate root-to-shoot ratio, planting them correctly, and planting them at the proper time. Moisture-retention techniques such as imprinting, pitting, mulching, and the use of tree shelters or shade cards may be employed. Overplanting to allow for some mortality may be less expensive than establishing a regular watering program (Burke 1998).

Irrigation assures maximum initial survival of plantings, extends the planting season, allows less drought-tolerant species to be planted, and promotes germination of seeds (Redente 1993).

The disadvantages of supplemental irrigation include the added labor and expense, the possibility that plants will be killed by overwatering, and the possibility that plants will grow shallow roots that may not allow the plants to survive when watering ends (Redente 1993). Surface watering may cause weed seed to germinate, and the weeds may outcompete native plants. In addition, surface irrigation may favor some species, such as grass, that outcompete other desired species, such as shrubs.

In the Mojave Desert, just 2 percent or less of the plants that did not receive supplemental irrigation have survived (Bainbridge and others 1992). Clary and Slayback (1984), on the other hand, determined that irrigation did not increase the survival of most Mojave Desert shrub species if they were planted during the late winter or early spring. Practitioners working in the sagebrush steppe have demonstrated that supplemental irrigation increased initial establishment and plant growth, but that after 4 years there was no difference between plants on irrigated plots and unirrigated plots (Doerr and others 1983). Some practitioners working in subalpine environments advocate watering plantings every few days during the dry portion of the growing season (Campbell and Scotter 1975; Hanbey 1992; Hingston 1982). Arid land restorationist Edith Allen (1993) suggests watering no more than would occur during a wet year.

If you do water plants, provide enough water to reach the deepest portion of the root zone, stimulating the root system to grow deeper rather than stimulating it to produce roots close to the soil surface. Deep watering can be achieved by repeated waterings or by leaving a drip system going for a longer period of time. For plants with deep root systems, the deep pipe method may be appropriate to deliver water straight to the lower portion of the roots.

3.12.2a Water Delivery Systems

Many techniques have been devised for catching water, moving it to restoration sites, and administering it to plants. Practitioners who apply a little ingenuity will probably think up a few more ways.

Hand Watering With Watering Cans

Watering cans are probably the most common tool for watering plants on remote sites. Watering cans can be filled in lakes or streams or in larger containers of water. David Bainbridge advocates using French watering cans because the long arching handle on this type of watering can is easy to balance (figures 3–140a and 140b). Usually, water is applied directly to the base of plants, taking care not to flood the rim of the planting depression.

Figure 3–140a—These watering cans have the “French” handle design— a long arching handle that balances nicely and prevents back strain.

Figure 3–140b—These plants are benefiting from watering at Lake Mary in the Alpine Lakes Wilderness, WA.

Clay Pots

In arid regions of Africa, unglazed, low-fire clay pots, such as terra cotta pots, are placed in the ground beside plantings with their rims near ground level. Water in the pots will seep slowly through the porous clay. Pots are refilled every 2 to 4 weeks, a time-consuming process. The drain hole in the bottom of the pot is plugged with silicone. A ceramic saucer or aluminum pie tin is placed upside down on the pot (as a lid) and weighted with a rock. Perforations in the lid will allow rainwater into the pot. The lid prevents evaporation and keeps animals from drinking the water or from drowning.

This method has met with success in arid environments. It works well in sandy, gravelly, or saline soils. The clay pot also helps filter saline water. After several years, the porosity of the pot decreases, but the porosity can be restored by reheating the pot.

Catchment Basins

This method lends itself to areas that require earth moving as part of site preparation. Large dish shapes, 30 feet (9 meters) in diameter or larger, are sculpted into the soil. These basins will prevent water from running downslope.

Deep Pipes

With this method, a long pipe 1 to 2 inches (25 to 50 millimeters) in diameter is driven into the ground beside the planting hole. Holes drilled in the side of the pipe next to the plant allow water to seep into the soil. This method is best for plants with deep root systems and requires much less water than other systems; 1 quart (0.95 liter) of water applied using this technique is equivalent to several gallons (about 12 liters) applied at the surface. In addition, plants often can tolerate saline water applied using this technique that they could not tolerate if the water was applied with surface watering.

Pipes can be 1 to 4 feet (0.3 to 1.22 meters) long, depending on how deep the plant's root system will grow. Perforations need to begin near the level of the transplant's lower roots and be spaced to the bottom of the pipe. PVC pipes last well, but may be difficult to remove if roots grow into the pipe through the holes. Thick paper tubes won't have to be removed, but may degrade too quickly. Pipes have a lid on top to keep out animals and debris. A lid made from screen will allow water to be poured through the lid. Pipes can be filled from a watering can that has its sprinkler head removed, or from an emitter sprinkling system.

Drip and Sprinkler Systems

Drip and sprinkler systems are installed with a network of hoses that deliver water to the site. Smaller hoses are placed at the base of individual plants or connect to sprinkler emitters that water a portion of the area. These systems may not be well suited for restoration projects because they require frequent maintenance:

- Sprinkler heads clog easily even when they have a good filter.
- Animals chew on the tubing.
- Ultraviolet light breaks down the plastics.

Unless the water is directed into deep pipes or allowed to run for long periods, it tends to stay near the surface, producing shallow-rooted plants. On arid land projects, sprinkler systems should be avoided because rapid evaporation will leave salts that are toxic to plants on the soil's surface.

Nursery and garden supply businesses carry irrigation supplies. The gravity-fed water systems used for firefighting can be modified to provide water for irrigation. Doing so involves a gravity sock placed in a creek or a porta-tank upslope that is connected to a sprinkler system or a series of hoses and a nozzle. These systems clog with sediment frequently, requiring regular maintenance.

Tree Shelters and Plant Collars

Tree shelters and plant collars are made of pipe, peat, waxed cardboard, or plastic. They are set into the ground during planting and protect plants from direct sun, grazing animals, trampling, and sand blast. Water can be poured directly into the shelter or collar. Arid land restorationist Jayne Belnap suggests watering at the rate of 1 quart (0.95 liter) every 2 to 3 weeks (Belnap and Furman 1997).

3.12.2b Obtaining Water

Irrigation water has to come from somewhere. This can be a problem at roadless restoration sites that do not have surface water nearby. Water can be flown or packed in to remote sites, but the possible expense, resource damage, and wilderness philosophy argue against this option.

Options for storing water include food-grade barrels retrofitted with a spigot and timer, or porta-tanks.

3.12.2c Superabosorbent Polymers

Some practitioners, especially in arid environments, have experimented by adding superabosorbent polymers (used in disposable diapers) to the soil when planting. The polymers absorb many times their weight in water, increasing the amount of water retained in the soil. Unfortunately, the polymers may limit root growth by holding water rather than releasing it to the plant (Bainbridge and others 1995). This method is worthy of further experimentation.

3.12.3 Preventing Animals From Damaging Plants

At some locations, animals that munch on vegetation or bark can quickly destroy the chances for restoration success. At other locations, animals are not much of a problem. Consult with local practitioners to determine whether plants need to be protected from animals and to learn of strategies that have been successful. The methods described below have been used with varying degrees of success.

3.12.3a Protective Coverings

Wire cages, tree tubes (figure 3–141), row covers, and tree wraps can protect a plant until it becomes established.

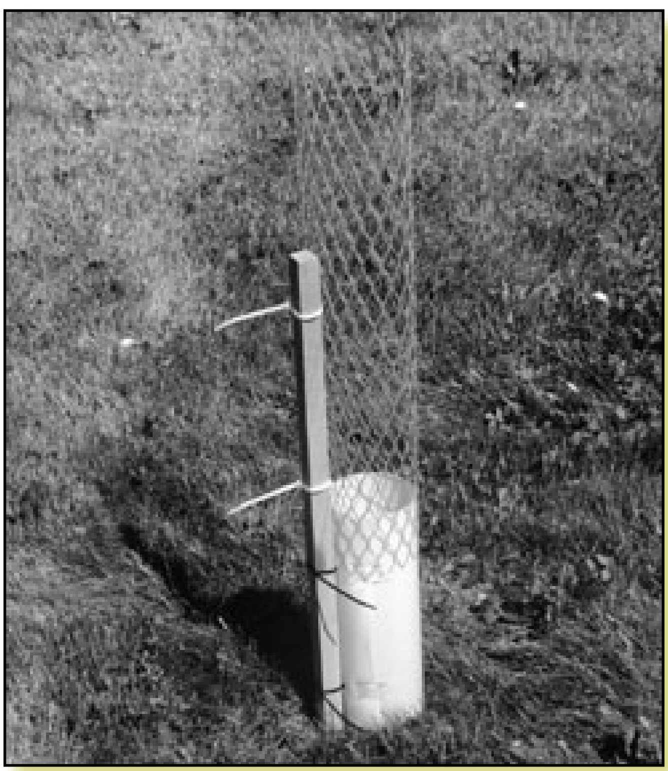


Figure 3–141—Protective coverings, such as this tree tube, are one way to prevent wildlife from eating seedlings.

Wire cages can be made from chicken wire. Tree tubes are available through forestry supply catalogs, and row covers and tree wraps are available through nursery supply catalogs.

3.12.3b Reduced Fertilization and Irrigation

Animals are attracted to the additional nitrogen in the tissues of fertilized plants. Cutting back on fertilization before outplanting will help, as will refraining from additional fertilization once seedlings have been planted. Animals also are attracted to well-watered plants. Reduce or stop additional irrigation once seedlings have been outplanted.

3.12.3c Animal Repellants

Bitter or hot animal repellants can be sprayed on foliage. Repellants need to be applied before animals discover the plants. Repellants will wash away during rain storms. A systemic repellant is available that can be added to the soil during propagation. This repellant will remain in the foliage for up to 5 years after treatment.

3.12.4 Signs

For most situations, signs will be needed to keep visitors from using your restoration site. Signs can be made of wood, Lexan, or Carsonite, a composite made from glass-fiber reinforced polymers. Match the type of sign (figures 3–142a, 142b, 142c, 142d, and 142e) to the setting and the type of user.

Even though we would like to think of signs as temporary, they probably will be needed over the long term unless the type of use has changed. Some people just won't get it (even with the sign). A good option for wilderness is a standard routed oak sign mounted on a short post or a tree. Use wording such as "Closed for Restoration." Refer to chapter 5, *Tools of the Trade and Other Resources,* for information on ordering Lexan signs.

Figure 3–142a—Routed oak signs provide a good long-term, low-maintenance way of signing closed areas.

Figure 3–142d—A map of the area being restored and an explanation of the project can help establish support for the closure.

Figure 3–142b—Small signs can be attached to posts or string fences to close an area.

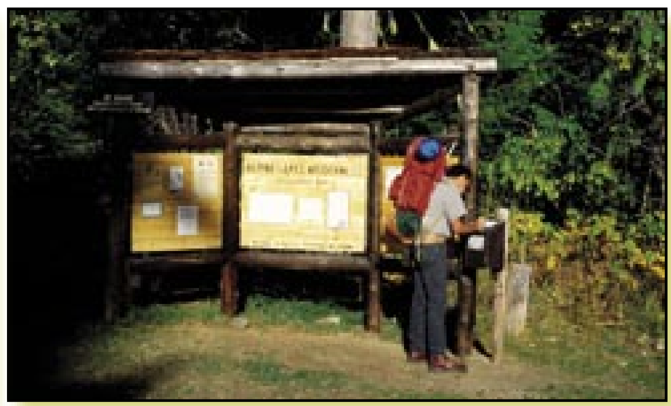


Figure 3–142e—A message and photos on the bulletin board at a trailhead are another way of helping visitors understand how they can help protect restoration sites and the wilderness setting.

Figure 3–142c—A wooden stake stamped with a boot print with a red slash across it also can be used.

In addition to signs at the restoration site, consider whether you need a poster at the trailhead or another location where visitors first enter the project area. The small information sign shown in figure 3–142d was left at the project area for several years to give plants in the restoration sites a chance to become established and to help campers find the designated campsites. The larger sign board (figure 3–142e) has been installed for many years and has undergone many revisions to help the public understand the information.

3.12.5 Regulations

Regulations are covered in detail in chapter 2, *Planning for Restoration of Small Sites in Wilderness.* At a minimum, a special order is recommended to prohibit entry into restoration sites. Rather than writing an order specifically for your project location, see if this prohibition can be in an order that applies to the wilderness or forest. Forest Service and Bureau of Land Management employees can obtain a good example of such an order from the Mt. Baker-Snoqualmie National Forest's Web site on their internal computer networks at *http://fsweb.f5.r6.fs.fed.us/orders/multi-forest/.* The four national forests of the Washington Cascade Range have a shared order that prohibits entering a signed restoration site.

Figure 3–143—Good documentation of restoration treatments is critical during monitoring. Intern Alexis Bachrach was able to satisfy the requirements for her college senior project by serving on a restoration crew and preparing the project documentation.

3.13 Documentation, Monitoring, and Adaptive Management

Monitoring project success is easy to overlook in restoration plans, but should be part of any restoration project, even at the planning stage. This is especially true given the highly variable and often experimental nature of restoration. Slight differences in site microclimate, soil chemistry, timing of field work, or perhaps even passing weather conditions can cause radically different results, even when nearly identical methods are used.

Monitoring may detect problems while there is still time to correct them and will provide a long-term record of results that others can refer to. Depending on the need and your budget, monitoring might be fairly simple (figure 3–143) or quite detailed. Monitoring might be qualitative, quantitative, or both.

In this section, we will explore different levels of monitoring performed by the Forest Service on restoration projects. We will consider factors involved in designing a monitoring program. Finally, we will review a simple monitoring protocol and suggest resources for selecting and designing more complex monitoring protocols. Sample monitoring forms are included in appendix E, *Forms.*

3.13.1 Adaptive Management

The goal of monitoring is to gain the understanding needed for a better job of management. Monitoring may result in midcourse corrections (figures 3–144a and 144b) to prevent further deterioration or to improve restoration success. If users continue to enter a restoration site for example, barriers or signs may need to be improved, or enforcement of regulations may need to be increased. Monitoring may show that excess water running through a site needs to be addressed. A failed planting may require another planting using a different approach or under different conditions. The key to adaptive management is taking new information, quickly devising a more successful strategy, and implementing it.

Figures 3–144a and 144b—This restoration site, first planted in 1980, started as a bare, compacted, and eroded slope. The site was treated with soil scarification, wildling plugs of partridgefoot (*Leutkea pectinata*), and jute netting. In the late 1980s, the site was reworked by scarifying soil between the plugs, adding rock for microhabitat and erosion control, and adding a layer of excelsior erosion control blanket. By 1993, when this photo (top) was taken, the partridgefoot was spreading. The erosion-control blanket prevented about 2 inches (50 millimeters) of additional soil loss (bottom).

Defining Validation, Implementation, and Effectiveness Monitoring

The Forest Service's *Land and Resource Management Planning Handbook* (FSH 1909.12) defines three levels of monitoring, each with slightly different objectives.

Validation Monitoring

Validation monitoring determines whether the initial data and assumptions used in development of the plan are correct. It examines the validity of standards and guidelines that drive prescriptions or activities.

Implementation Monitoring

Implementation monitoring determines whether plans, prescriptions, projects, and activities are implemented as designed. It examines the quality of the field work application of the project plan.

Effectiveness Monitoring

Effectiveness monitoring determines whether plans, prescriptions, projects, and activities are effective in meeting their objectives. It compares the work accomplished to the project's short- and long-term objectives.

3.13.2 Determining Levels of Monitoring

Anyone developing a monitoring plan or procedure for restoration projects should have a clear idea of the levels of monitoring that are needed and the degree to which they should be emphasized. If plans for the project were based on little or no field experience, validation monitoring may be a high priority. Likewise, if work is being done under contract or by volunteer crews, implementation monitoring may be an area of concern. A high level of effectiveness monitoring should be included in any restoration project. Because most restoration projects won't be completed for many years, effectiveness monitoring allows procedures to be adjusted to fit site-specific conditions. Effectiveness monitoring is an integral part of implementing the project activities.

Determining the Need for Validation Monitoring

Validation monitoring should be included to the extent that the project can be used to validate the standards and guidelines that have driven the project. The monitoring should include a sound accounting of the project's scheduling, materials, and so forth, as well as an accounting of any significant difficulties or constraints that arose. This might involve simply taking notes or preparing a narrative summary of the project's progress, or it may involve a more formal analysis.

Validation monitoring is especially important if the restoration project is responsive to a land-management plan or other decisions that were based on an environmental impact statement. In cases where a project cannot reasonably achieve objectives set forth in a land-management plan, validation monitoring may dictate further NEPA analysis, such as a forest plan amendment. Monitoring may provide the feedback needed to correct policy or regulations.

Determining the Need for Implementation Monitoring

Implementation monitoring will depend on the amount of detail used in planning the project, as well as the degree of flexibility built into the plan. This kind of monitoring requires that the project plan include fairly detailed specifications, especially for structural work such as constructing checkdams, backfilling eroded areas, installing erosion-control netting, and so forth. In essence, implementation monitoring can be seen mainly as inspection to ensure the quality of work. The inspection should be used to ensure that the end product meets objectives, not merely to show how and where the project fell short.

Particularly when working with volunteers, Forest Service crews, or other groups without a formal contract, implementation monitoring can be used to adjust specifications during implementation of the project. Doing so is especially important when workloads prove greater than anticipated, weather prevents work from being accomplished, or other problems arise. In general, the greater the scope and complexity of the project, the greater the importance of implementation monitoring.

Determining the Need for Effectiveness Monitoring

Typically, monitoring restoration sites entails monitoring the condition of site vegetation. The methods of monitoring or the indicators selected will vary with the type of vegetation involved and the techniques used to reestablish natural vegetation, as well as with the overall goals and objectives of the project.

The scale of the project will determine to some extent the kinds of monitoring techniques that should be employed. For smaller projects, it may be feasible to take detailed data on every plant on the site; for larger projects, permanent plots or random sampling techniques may be preferable.

The species of plants involved may dictate certain methods of monitoring. For example, different monitoring strategies might be employed when working with trees rather than grasses. With grasses, percent cover may be an excellent indicator of success, while with trees, height may be a better indicator. When direct seeding is used, a good indicator of success might be the number of stems per square foot or square meter. Percent survival would be a better indicator of success when planting plugs (figure 3–145).

Some possible indicators commonly used by ecologists include: total percent cover, percent cover by species; plant height; number of stems per given area, stem diameter, stem or plant size class, and survival rates for plugs or seedlings. Some indicators are more qualitative in nature, such as lists of species composition or classification of plant vigor. Although quantitative measures are more commonly used in monitoring, qualitative measures, such as vigor classification, can be very important. Standard vigor classification schemes can indicate whether plants are able to produce viable seed,

Figure 3–145—Tracking percent survival is easier if the site broken into smaller units, such as the area between checkdams. This project was at Lake Mary in the Alpine Lakes Wilderness, WA.

an indicator that a site may be on its way to becoming self-maintaining.

Factors such as ongoing erosion, effectiveness of erosion-control structures, and effectiveness of barriers should be monitored. An effectiveness monitoring protocol also should consider whether use has been displaced, and if so, what the impacts of the displaced use might be. Use may shift locally, to other nearby locations, or to areas farther away.

Other Monitoring Design Considerations

In some cases, information such as percent cover by species may not be important. A project may aim simply to eliminate human use and allow natural recovery. In that case, the percent screening between the work site and a passing trail may be the best indicator of success. On the other hand, if a project aims at true ecological restoration, technical factors, such as soil bulk density or litter depth, may be better indicators of success.

In projects that do not aim for full restoration in the short term, monitoring may be best designed with incremental objectives in mind. For instance, rebuilding soils or soil structure may be a more attainable goal than reestablishment of natural vegetation. In such projects, monitoring the depth of trail erosion (or the level of deposition behind checkdams) might be indicators of success. In other cases, qualitative measures could be used as indicators of success—perhaps simply monitoring public compliance with “Keep Off” signs, or monitoring the reappearance of fire rings or litter.

Some projects may focus on eradicating weed species or altering vegetative composition. The percentages of different species growing on the site, or the mere presence of certain species, may serve as the best basis for monitoring. Projects that transport plant material or soil into the wilderness should always include some monitoring for the accidental introduction of nonnative species.

In any case, the project’s goals and objectives should determine the levels and methods of monitoring used. Although many projects will focus on effectiveness monitoring, some combination of implementation, effectiveness, and validation monitoring is desirable.

3.13.3 Establishing Monitoring Procedures for a Project

Solicit interdisciplinary input when establishing procedures for monitoring (figure 3–146). For validation monitoring, consult trail maintenance and design specialists, wilderness specialists, hydrologists, engineers, botanists, recreation planners, NEPA specialists, or others with technical backgrounds.

Figure 3–146—Three separate attempts have failed to restore this wilderness campsite. Monitoring can help us learn from our failures as well as our successes.

For effectiveness monitoring, consult resource specialists with direct working knowledge of the site and the project's physical and social objectives, such as botanists, ecologists, wilderness rangers, soil scientists, range conservationists, and others with similar expertise. Workers with hands-on field expertise need to be involved, because effectiveness monitoring tends to be the most detailed and take the most time of the three types of monitoring.

3.13.4 Incorporating Monitoring Into a Project

Project monitoring will help determine whether the site restoration goals have been met.

Planning Phase

A critical aspect of monitoring is the need for feedback to be provided in sufficient detail and in a timely fashion. Validation monitoring may begin during a project's initial planning stages. If a project's costs or its logistical problems begin to seem unreasonable, it may be necessary to reexamine standards and guidelines that mandate the proposed action. As a project progresses and implementation and effectiveness monitoring are taking place, validation monitoring should be used to ensure that policy matches reality. Validation monitoring can contribute to policy change at high levels that can save large amounts of work time and funds.

Implementation Phase

While validation monitoring may continue throughout the project's life, implementation monitoring becomes key during all phases with on-the-ground work. Implementation monitoring should guide daily work schedules, ensuring high-quality results. Implementation monitoring must be ongoing with a short response time, enabling crews to adjust their work methods and allowing project leaders or contract administrators to make corrections to schedules or specifications as needed. Remember that the goal of implementation monitoring should be to ensure that objectives are met, not to analyze why they were not.

Implementation monitoring includes documentation of the work accomplished: location of restoration sites, stabilization treatments, soil treatments, planting treatments, plant protection measures, signs, and so forth. Photopoints should be established that document conditions before work began, and after the treatment is in place. These photopoints will continue to be used as part of effectiveness monitoring.

As part of implementation monitoring, consider having crews keep a daily journal of work activities and other useful observations. For example, if crews keep track of how much time they spend on each component of their work, the records will help you judge the accuracy of your original budget estimates. Consider incorporating additional information in the journal. This information might include daily encounters with visitors, campsite occupancy data, or even wildlife sightings. A well-kept field journal can help answer questions years after a project has been completed (see figure 3–143).

Followup and Maintenance Phase

Effectiveness monitoring may begin while the project is being implemented. However, the most important factor when incorporating effectiveness monitoring is to think long term (figures 3–147a, 147b, 147c, and 147d). Restoration often spans many years or decades. A project that appears to be an immediate success or failure may not be over the long term. Effectiveness monitoring may be done annually, on a 3-year rotation, or over even longer intervals. Annual monitoring may be appropriate during the early years of a project, but monitoring may be scaled back during later years. In all cases, effectiveness monitoring should be done in a fashion that allows managers to respond to problems with project design and to improving or deteriorating conditions.

This series of photographs documents 8 years of progress during restoration of one of the two trails accessing Lake Mary in the Alpine Lakes Wilderness, WA. The restoration crew installed rock steps on the open portion of this trail that is used only by hikers. The other half of the trail was restored using checkdams, fill, greenhouse-grown transplants, and an excelsior erosion-control blanket.

Figure 3–147a—A high school student had the pleasure of planting the plants he grew for his senior project.

Figure 3–147b—The erosion-control blanket is the most obvious sign of restoration in this 1995 photo.

Figure 3–147c—Conditions were still good in 1997. Two rock steps had come loose and needed fixing or replacement. Plants were surviving and erosion was largely stabilized. A second application of erosion-control blanket would be beneficial.

Figure 3–147d—By 2002, the rock steps really needed some help. The vegetation continued to mature and fill in. Other plants seeded themselves from the nearby meadow and had become established.

Monitoring Methodologies

Monitoring methodologies range from taking simple qualitative observations to more complex quantitative measurements. Design your methods based on the questions you need to answer and the resources available to accomplish the work. It helps to break restoration sites into smaller units for documentation and monitoring. For example, you might keep track of the number of plantings between each check-dam, with the checkdam serving as a reference point. Appendix E, *Forms*, contains sample forms you can modify when designing your own approach.

A simple approach is to notice and document obvious factors that contribute to the project's success and trends that point toward recovery or failure. Most wilderness restoration projects are so small that the entire site can be evaluated. Sample questions might include:

- Is water flowing around or through the site as planned?
- Are erosion-control measures working?
- How many transplants have survived?
- What seeded species have become established?
- Which species have volunteered?
- What is the overall vigor of each species? Are the plants stunted? Discolored? Flowering? Fruiting? Spreading? Is an additional treatment needed to improve plant health?
- Are plants being disturbed by animal activities such as herbivory? Do such problems need to be mitigated with an additional treatment?
- Are sites being disturbed by human activities? Does this disturbance need to be addressed through further engineering, education, or enforcement?
- Are signs and barriers still in place?
- Does the site include any introduced plant species (weed them out!) or diseased trans-plants?
- What are the changes in species composition?
- What is the percent ground cover? Canopy cover?
- Are plants at the prescribed stocking levels? Do you need to plan for additional plantings?

Some projects might require more detailed methods of monitoring. Techniques that have been used to measure species composition and percent cover include line-intercept transects, radial transects, and quadrats (Potash and Aubry 1997; Redente 1993; Rochefort 1990). Projects outside wilderness might use engineered structures to measure active erosion. Some projects may track individual plantings. Larger projects will require a sampling procedure (figure 3–148) rather than a complete census. An ecologist and statistician can help you design appropriate protocols.

Figure 3–148—Wilderness research scientist David Cole, coauthor of this guide, goes to extraordinary lengths to prevent further impact to vegetation while counting plants during a study in the Eagle Cap Wilderness, OR.

Designing and Analyzing Vegetative Sampling Procedures

Two standard texts explaining vegetative sampling procedures may help:

- *Aims and Methods of Vegetation Ecology* by Meuller-Dombois and Ellenberg (2003) is the classic text on selecting and implementing an appropriate vegetation sampling technique based on your analysis goals. Fortunately, this text was recently brought back into print.
- *Statistical Ecology: A Primer on Methods and Computing* by Ludwig and Reynolds (1988) is a good companion to the previous text that will help explain the statistical basis for applications of ecological sampling.

The Bureau of Land Management has an excellent free publication, *Sampling Vegetation Attributes* by Coulloudon and others (1999), that can be ordered hard copy or downloaded from *http://www.blm.gov/nstc/library/techref.htm*.

Recording and Reporting Monitoring Results

When designing the monitoring for a restoration project, include concrete steps that will be taken to manage and report on the data collected through the monitoring process. Think ahead to consider how monitoring results may be a catalyst for changes in policy, ongoing management of your project area, or the design of future projects.

Information related to validation monitoring should be passed along to appropriate decisionmakers or planning staff. Any significant discrepancies found through validation monitoring could be included in annual forest plan monitoring reports or similar reports that will bring these situations to the attention of others.

Information pertaining to implementation monitoring needs to be acted on promptly. Problems should be identified and explained to contractors or work crews, noted in work logs or inspection reports, and dealt with in a manner that will ensure situations are corrected before further loss of productivity or project quality. It is important to document the findings of implementation monitoring properly, but it is perhaps more important to relay those findings in a timely manner to persons responsible for implementing the work.

Data collected during effectiveness monitoring may be the most difficult to analyze, requiring technical skills and a long-term vision of how project objectives will be met. Because data collection will be ongoing in most cases, it may be wise to develop a database (or at least a good filing system) for data that will accumulate over several years. The data should be summarized periodically and used in planning maintenance of this project or similar projects. Summaries of this kind of data will be especially useful to those developing budgets and work plans or to resource specialists involved in restoration. Consider making this data more widely available to researchers and practitioners of restoration. Refer to appendix D, *Case Studies*, for an example of a monitoring report.

Monitoring Summary

A key element to any restoration project is developing a monitoring process. Monitoring should be thought of in terms of the three types: validation, implementation, and effectiveness monitoring. The monitoring process should be tailored to the objectives and scope of the project, as well as to the ecological and vegetative components of the site. Technical help from specialists should be used to develop specific procedures for each project. If the true benefits of monitoring are to be realized, data from monitoring must be analyzed, summarized, and reported to appropriate personnel.

3.14 Project Maintenance

Plans for restoration projects should include time and money for maintenance. Identifying funding can be tricky, because a restoration project may have a special project funding source that ends once the initial work has been completed.

Based on either formal or informal observations and monitoring, you will determine whether your treatments are likely to succeed. If the desired plant species are thriving, soils are stable, and the signs and visitors are in the proper places, you can jump for joy and walk away. But some of your treatments may need additional work to address ongoing erosion, lack of plant vigor, or ongoing impacts from human use.

Because of high turnover among seasonal staff, new employees may take over a long-term maintenance program. It is important to document the site-specific maintenance tasks in an action plan, including any specific concerns and where signs need to go. Otherwise, your new wilderness rangers will visit your project area and be unable to spot details that need attention.

3.14.1 Site Management

Site maintenance might require ongoing treatments (such as irrigating and mulching plantings, or amending the soil), repairs, or even modifications to the treatment.

3.14.1a Irrigation

Plantings may need several years of watering before deep root systems become established. Unless plantings are watered by hand, irrigation systems will need regular inspection to fix leaky, broken, or malfunctioning components. An irrigation log should be kept to document the amount and frequency of watering.

The Respect the River program on the Okanogan and Wenatchee National Forests has a unique approach to getting this job done—restoration sites have a small sign inviting forest visitors to help out with watering! This approach seems to be working and helps visitors become part of the solution (figure 3–149).

Figure 3–149—Visitors can help with watering if they are encouraged to do so.

3.14.1b Mulching

Depending on the material, mulch loses its effectiveness after a few years. Unless plantings have become fairly well established by then, a new layer of mulch may have to be added to preserve soil moisture and to provide protection from the elements.

3.14.1c Soil Amendments

If plantings look stunted or discolored, this may be a sign of a nutrient imbalance. A feeding of nitrogen may be needed because nitrogen disappears rapidly from the soil. Until the site has an adequate supply of litter, native nitrogen sources may be lacking. See section 3.2.3c, *Amending Altered or Depleted Soils*, to determine an approach that is appropriate for your site.

3.14.1d Stabilizing Erosion

Ongoing erosion damage could take many forms, requiring different solutions. Running water may be causing further damage to a restoration site, or perhaps your attempts to move water away from your site have created a new problem somewhere nearby. Maintenance work might include directing water away from a site, spreading water out more effectively across a site, repairing malfunctioning erosion-control structures such as siltbars or checkdams, adding structures to slow water and collect silt, or adding mulch.

3.14.1e Wildlife Damage

Structures put in place to prevent animals from eating plants may need to be repositioned or replaced. Nutrient-rich plantings can be attractive to animals. Ants can march away with all your seed. Section 3.12, *Plant Protection and Establishment*, offers suggestions for managing these problems.

3.14.1f Frost Heave

Some plantings may be forced out of the ground by frost. If the plants are still alive, they will need to be reset. Set plants back into a shallow depression and firmly compress the soil around each plant. Additional mulch also may be applied to prevent frost heave.

3.14.1g Interplanting or Replanting

Additional plantings may be necessary if goals for the desired abundance and species diversity have not been met. But this problem may be an indicator that Mother Nature has different ideas of what is feasible than you do. Before replanting, work with your team to figure out what went wrong and how it might be corrected. The *Limiting Factors* chart in appendix A, *Treatments To Manage Factors Limiting Restoration*, will help you think through such problems.

Here are some examples. Perhaps the reference community is not appropriate for your site—a plant species only found in open meadows may not survive in shade (The author speaks from experience!). Perhaps you were trying to move toward the reference condition too quickly and need to start with early successional species. Perhaps the plant stock type was not well suited to your site. The list goes on and on. If a planting has failed to perform, do your best to figure out why, devise a new strategy, and replant.

It may be that adding additional species would help meet the reference community's plant structure. Try direct sowing seed onto your site during the same period when seed would fall to the ground naturally, or use other onsite propagation techniques. You may need to collect additional plant material for propagation offsite.

3.14.1h Exotic Species

Be sure to have a botanist or someone else who can recognize wayward plant species visit your site. Weed out any exotic species! Record their loathsome presence in your monitoring logs, and try to determine how they got into the wilderness. Chances are the invaders stowed away with plant materials or soil brought in from offsite. Or you may have released dormant seed from the soil's seed bank when you loosened and watered the soil.

One helpful tool is a weed finder—a little field guide with colored photos of potential weed species for your site (figure 3–150). Include photos of plants at different life stages—seedlings, plants in flower, and plants in fruit. This guide might include any nonnative plant species found

Figure 3–150—Site monitoring and maintenance require careful attention to spot introduced plant species. An area-specific weed finder depicting nonnative species that may have been stowaways on plant stock or other materials will help members of your crew.

growing near where your plant materials were propagated and stored. It should also include any weed species known to be in that portion of the backcountry or at the trailhead. This weed finder will be a tremendous asset to anyone who checks the site but lacks botanical expertise.

3.14.2 People Management

Managing continuing recreation use of the area is another part of the maintenance battle. Your goal is to concentrate the use where you want it and to keep the use off of your fragile restoration site.

3.14.2a Signs

Signs need to be maintained until they are no longer needed. Just one group tying stock up in your restoration site might undo thousands of dollars of backbreaking work in two quick hours—the voice of experience again. If your project is in a remote area, but not in wilderness, it may be helpful to lay in a small stash of extra signs there, or to have visiting personnel carry extra signs so problems can be remedied when they are spotted.

At some point, use patterns at a project site may have established themselves so that the signs are no longer needed. For example, it is more important to keep signs at the site when plantings are small than after they have become established. If you take signs down, monitor your success fairly soon to determine whether they may need to be replaced.

3.14.2b Barriers

It may be necessary to maintain or add barriers to keep folks where you want them. Some barriers may get rearranged or carted off. Perhaps they just weren't big enough in the first place.

3.14.2c Replacing Structures That Fail

Structures installed to check erosion, or to harden campsites or trails, can fail. It may be necessary to reposition or replace some of your work.

3.14.2d Maintaining Social Trails

Part of your planning effort was to figure out which social trails to keep. Provide these trails with enough maintenance to keep use on the trails, and off fragile vegetation. This may mean providing drainage, cutting brush, cutting fallen logs (figure 3–151), or maintaining barriers.

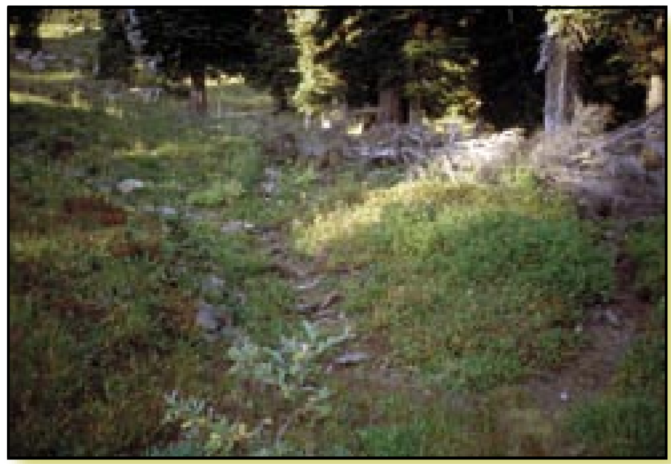


Figure 3–151—The restored trail to the left was recovering quite well until the heavily limbed subalpine fir fell across the main social trail to the right. Because the fallen tree was on a social trail, it wasn't included in the maintenance contract in the Alpine Lakes Wilderness, WA. Wilderness personnel removed limbs with a pruning saw, hoping to redirect use onto the proper trail.

3.14.2e New Impacts Caused by Displaced Use

Preventive maintenance should be done quickly if impacts shift to other locations. For example, users may decide to start new campsites, or walk across vegetated areas, forming new trails. It may be necessary to implement a variety of strategies to absorb the change appropriately, or to stop the damaging practice.

Reassessing the Minimum Tool

Sometimes, creating an unnatural appearance can help stabilize or close a restoration site (figure 3–152). Signs may need to be heavy handed at first to gain user compliance, but signs don't need to be on every closed area once vegetation discourages use. Perhaps a facility, such as a hitchrack, was provided to concentrate impacts but use patterns or improved user choices had made it unnecessary. Consider when it may be appropriate to peel back some of the obvious signs of the restoration work so your efforts become "substantially unnoticeable," meeting the intent of the Wilderness Act of 1964.

Figure 3–152—Use was shifted off this fragile meadow onto a hardened surface by laying a row of rock to block the trail and building cairns on the alternate route. About 30 years later, vegetation has grown in between the rocks, but the rocks themselves create an unnatural appearance. About half the rocks were removed and the resulting divots were filled with soil to protect exposed roots. Someday, perhaps the remaining rocks can be removed from this restored trail at the Enchantment Lakes in the Alpine Lakes Wilderness, WA.

3.14.3 Scheduling Maintenance

In general, maintenance needs to be more intensive during the first few years after a project while problems are being addressed and new plantings are gaining a toehold. Afterward, maintenance may become more periodic. Keep in mind that even something as simple as a missing sign can have great consequences.

It is important to visit restoration sites when runoff is at its peak to assess erosion problems. If the public frequents the area during snowmelt, it is important to assess potential problems then. It also is a good idea to check restoration sites during peak-use periods when crowding can lead to problems. If ongoing irrigation is critical to the project's success, the site needs to be visited during droughty times of the year.

3.14.4 Concluding Thoughts on Maintenance

Restoration work requires long-term maintenance. While the intensity of maintenance tapers off with time, most projects require upkeep for many years, if not decades. Remember to leave good tracks for those who follow in your footsteps, and have fun and stay humble in your role as wilderness guardian.

Chapter 4

Restoration Program Development and Support

Even with volunteer assistance, restoration programs require a big commitment of our corporate energy and funding. This section discusses ideas that will help you build your program. Most Forest Service wilderness restorationists do not have a consistent program, but lurch from project to project as funding or other opportunities present themselves.

4.1 Funding, Workforce, and Partnerships

There is no magic funding source for wilderness restoration projects—roll up your sleeves and figure out your best options. Networking with other wilderness restorationists will help you see how they plan their budget and workforce. Let your allies know what you are seeking; you may gain ideas from other specialists or citizen advocacy groups. Learn by doing—keep good records of your costs, including the hidden costs such as your staff time, to refine future project planning.

4.1.1 Funding

If you are lucky, you are planning a restoration project that already has some funding. It's more likely that you will need to seek out sources of funding and leverage your limited budget with volunteer labor (figure 4–1). Small projects can be accomplished with your existing workforce using appropriated dollars to cover a few material costs. Obtaining additional funding can be discouraging—the Forest Service has no readily available pot of funds for wilderness projects. Many units seek outside funding sources, such as grants for their projects.

Figure 4–1—Two teenage volunteers on a Student Conservation Association high school work crew pause while hauling fill.

4.1.1a Forest Service Sources of Funding

Recreation—If the impacts you are treating are related to recreation, the recreation budget is an appropriate funding source.

Recreation Fee Dollars—The national recreation fee programs may allow funds to be used for restoration projects. If your local fee program's business plan allows for restoration, you may be able to lobby for some funding.

Capital Investment Program (CIP)—Wilderness restoration projects can be submitted to the CIP program. There is no telling what year (or decade) your project will rise to the surface for funding. But this is a nice funding source when it comes through, because the funding is in place for several years.

Soil and Water—If the impacts at your project location are contributing sediment to streams with native species of fish, approach your fish biologist or hydrologist about tapping into soil and water funds.

Knutson-Vandenberg (KV) Act Funding—Outside wilderness, a restoration project may be part of the mitigation from a timber sale, such as restoring a logging landing back to a trailhead. Include this mitigation in the timber sale decision and make sure it is included in the KV plan. Be forewarned that "nonessential" KV items often remain unfunded.

4.1.1b Other Funding Sources

Federal agencies are not eligible to compete for many grants, but you may be able to partner with a not-for-profit organization, such as a native plant society, to help acquire funds. Some States have grant programs that fund a variety of improvement or restoration projects on public lands. If you apply for grants, develop your proposal to give you as much latitude as needed. For example, if you only include labor and materials in your grant, you may not be able to fund important aspects of your program, such as planning, transportation, and equipment. Your local library may have information on sources of grants for restoration projects.

4.1.2 Budgeting

Project planning is the first cost incurred in a restoration project and can be the most difficult to fund. It may be possible to attract the help of kind-hearted specialists pining for a wilderness trip.

In general, the project implementation budget is developed based on materials, equipment, and labor. You may also want to budget for training. Materials include items such as plant materials, erosion-control materials, soil amendments, and signs. Equipment will include any tools, camping supplies, and items needed for transporting materials or workers.

For projects outside wilderness, labor costs are often relatively low because of the efficiency of motorized equipment and large machinery. In wilderness, labor costs are much higher, but can be offset with volunteer labor. Don't be surprised when a task takes far longer than envisioned. For example, if your crew is using buckets to collect soil for fill, it may take up to a week to collect enough soil to restore one site or closed trail.

The following box lists potential budget items. While this list is not exhaustive, it will help you think of a variety of costs. Keep in mind that it is far more efficient to overprepare than to be underprepared. Having a thorough site assessment and restoration plan will make the budgeting process fairly easy. Planning also helps to set priorities for each component of the project so that the most important portions of the project are finished first, an important factor if funds run short and the project cannot be completed.

Items To Consider Including in a Restoration Project Budget

This summary is based on Belnap and Furman (1997) and St. John (1995).

Planning Phase

- Collecting and analyzing wilderness inventory or monitoring data.
- Site assessment (personnel wages and per diem, soil samples, species lists, mapping).
- Developing a proposed action and site prescriptions.
- NEPA analysis and consultation with other agencies.
- Developing a budget and procuring funding.
- Recruiting labor.
- Training.

Implementation Phase

Transportation costs: May include stock, vehicles, helicopters.

Labor costs: May include volunteer stipends and housing.

Plant material collection: The main cost is travel time. It may be necessary to make several trips at the proper time for each of the species being collected.

Plant propagation: First-year plants may cost 55 cents to $2. Larger plants will cost considerably more. Additional costs may include delivery, seed cleaning, seed testing, seed storage, and plant holding costs. Mt. Rainier National Park estimates the full cost of propagation to be $4 per plant.

Tools

- Buckets
- Come-alongs
- Gardening forks
- Gloves
- Hand pruners
- Hardhats
- Kneepads or kneeling pads
- Log carriers
- Loppers
- Mallets
- McLeods
- Pick hoes or trowels
- Picks
- Rebar
- Rock bars
- Safety glasses
- Saws
- Shovels
- Sickles
- Sledge hammers
- Soil thermometers
- Tree spades
- U-bar diggers

Site stabilization and preparation: Retaining devices such as logs or rocks, fill material, topsoil, soil amendments, and plastic sheeting.

Camping equipment: Any additional gear that will be needed, plus replacement for items that will become unusable because of wear and tear. Crews that are out for a long time will want larger tents, perhaps a screened tent, and a means of storing food away from critters. In colder, wetter climes, a portable heater, such as a propane heater, will help to dry out wet gear from day to day. Wet weather is a strong possibility when planting during the rainy season.

Site protection and plant establishment:

- 2- by 2-inch (50- by 50-millimeter) stakes
- Barriers
- Devices to prevent animals from eating seed or seedlings
- Erosion-control blankets
- Fertilizer
- Irrigation devices
- Jelly-roll fabric
- Parachute cord
- Plant tubes
- Rooting hormone
- Shade cards
- Signs
- Shade cloth
- Transplant shock fluid (Upstart)
- Wire staples (for securing erosion control blankets)

Crew training: This could vary from on-the-job training to sending crew members to restoration workshops or having them visit successful restoration projects.

Monitoring and Maintenance

Provide regular monitoring and maintenance for several years after implementation and at less frequent intervals afterward. Also provide public contact and enforcement.

Ongoing maintenance supplies: signs, erosion-control materials, tools, and possibly fertilizer (until an organic soil layer is reestablished).

4.1.3 Workforce

If you do not have a restoration program in place already, it will take a little extra effort to develop your workforce. Skill development begins during the planning phase—take the time to educate your team if they haven't already been involved with restoration projects. Team members will benefit from reading this guide and other literature relevant to your habitats and plants, by listening to talks by other successful restorationists, and by attending a restoration course. You might consider inviting restorationists to provide training or present a case study for your team and work crews.

Don't just assume that the trail crew or wilderness crew will make a good restoration crew, although they certainly will have good skills to contribute. It helps if your restoration crew has lots of perseverance. The work goes slowly and is hard on the back and knees (figure 4–2) because of all the bending and kneeling. The crew needs an eye for detail, precision, and thoroughness in tasks such as installing erosion-control features, identifying plant species, and transplanting plants. The crewleader needs to have good technical skills, be good at quality control, and work well with people. Crewmembers with a background in gardening, landscaping, or working with plants are good choices. Folks more interested in moving through a project quickly are not good choices. Even motivated workers may need a pep talk to get through the more monotonous or uncomfortable parts of a project.

Give the crewleader time to become prepared. Perhaps the crewleader was involved in the planning and already has ownership in the project. Consider sending the crewleader to a restoration training course at the Arthur Carhart National Wilderness Training Center in Missoula, MT. Other ways to increase a crewleader's skills include reading publications such as this guide, attending other restoration workshops (check with the Society for Ecological Restoration), and visiting other units with successful restoration programs. Take a reconnaissance trip to the restoration site with your crewleader so the leader clearly understands each aspect of the project.

Figure 4–2—All restoration projects include lots of uncomfortable bending and endlessly monotonous tasks—choose your crew carefully.

Once the crew is onboard, provide them with on-the-job training. Show them pictures of the various steps of the restoration process, and explain the principles involved in each step. Be sure to include any other expectations you may have for the project, such as practicing *Leave No Trace* principles, preventing further damage to the project site, working a split shift to beat the heat, or any other concerns. If your work crew is small, consider recruiting a larger group during the first few days to help move heavier items (logs and rocks) and to create a sense of momentum. Unless your project area is close to a trailhead, consider having the crew work long hitches to maximize the hours they spend working on the project relative to the time spent in travel. If you aren't supervising the project yourself, be sure to at least visit while the work is underway for the sake of the crew's morale and to allow you to make any midcourse corrections that may be needed.

4.1.4 Partnerships

Lots of folks care about wilderness and restoration of damaged wild places. Project dollars can be maximized and public good will can be enhanced by building partnerships. This section specifically discusses the role of volunteer partnerships. The next section discusses the use of professional services.

Volunteer relationships can be developed for any aspect of a project—from monitoring and planning, to growing plants, to project implementation and maintenance. Depending on the skill level of the volunteers, you will need to invest a considerable amount of mentoring, training, coordination, supervision, and quality control when working with them. Responsible, motivated, mature individuals are almost a prerequisite for restoration projects; avoid using the 1-day volunteer Scout or school group as your planting crew unless they already have a lot of ownership in the success of your project.

There are many ways to recruit volunteers. Tap into organizations in your area that enjoy service projects. Examples might include hiking clubs, the Back Country Horsemen, environmental clubs or organizations, and native plant societies. Many college students need internships. Interns could help during the various phases of a restoration project (figure 4–3). Also consider recruiting graduate students who need a thesis project. Build relationships with teachers or professors who might be a source of interns or graduate students.

Be creative and develop any natural alliances. For example, one of the wilderness rangers in the Selway-Bitterroot Wilderness is a retired school teacher from Iowa. She developed a partnership where teachers from Iowa

Figure 4–3—Students fulfilling internships can be motivated restoration workers. If they volunteer, do your best to defray their expenses.

receive continuing education credits for helping with wilderness restoration projects. The following section lists several national organizations that act as clearinghouses for volunteers.

Volunteers need care and tending. Be sure they receive the rewarding experiences they are seeking. When recruiting volunteers, let them know how important their contribution will be to wilderness management. Provide for their basic needs by providing assistance with transportation, housing, and gear. Offer a stipend if you can.

Treat volunteers with the same respect you would a paid crew and be clear on relationships, including who is in charge of a project. Handle differences of opinion or morale issues with good cheer. While volunteers are working on the project, arrange for site visits from dignitaries, such as the district ranger. If an assignment takes longer than 5 days, include free days for volunteers to take time off and explore or relax. Counsel students regarding career ladders and career options; offer to write letters of reference. Recognize the crew's accomplishments with nonmonetary awards, an end-of-project social event, and followup correspondence or pictures.

4.1.5 National Sources for Recruiting Wilderness Volunteers

Costs were based on 2003 price schedules.

American Hiking Society (AHS) Volunteer Vacations
1422 Fenwick Lane
Silver Spring, MD 20910
Phone: 800–972–8608
Web site: *http://www.americanhiking.org*
E-mail: *shearn@AmericanHiking.org*

Types of volunteer offerings: 1- or 2-week trips with an emphasis on trail work and shelter maintenance. This might work well for a trail relocation project where restoration of the old trail is part of the project design.

Agency expectations and costs: Free to the agency. The agency provides at least partial supervision (directing work) and transportation from the airport, as well as group cooking supplies, tools, safety equipment, two-way radios, and first-aid supplies. An AHS crewleader can be requested to take care of logistics such as menu planning, grocery shopping, and camp management.

Cost to volunteers: $80 for members and $100 for nonmembers, plus transportation costs.

Earthwatch Institute
3 Clock Tower Place
Suite 100, Box 75
Maynard, MA 01754
Phone: 800–776–0188
Web site: *http://www.earthwatch.org*
E-mail: *info@earthwatch.org*

Types of volunteer offerings: Trips are to conduct meaningful field research projects. Volunteer fees help fund the research. This program is designed to assist researchers who have less access to funding.

Agency expectations and costs: The agency provides a salary for principal research personnel. The agency provides food, lodging, and onsite transportation.

Cost to volunteers: Varies by project, ranging from $700 to $2,500. For example, an average 2-week trip costs $1,800. Food and accommodations are included in the cost.

Elderhostel
11 Avenue de Lafayette
Boston, MA 02111–1746
Phone: 800–454–5768
Web site: *http://www.elderhostel.org*
E-mail: *registration@elderhostel.org*

Types of volunteer offerings: While most of their trips are for educational purposes, Elderhostel does offer service trips (and backpacking trips).

Agency expectations and costs: The agency provides supervision and tools.

Cost to volunteers: Costs vary, but $115 per day appears to be an average. Limited scholarships are available.

Sierra Club Volunteer Vacations
85 Second St. 2d Floor
San Francisco, CA 94105
Phone: 415–977–5500
Web site: *http://www.sierraclub.org*
E-mail: *national.outings@sierraclub.org*

Types of volunteer offerings: Service trips run from 7 to 10 days and help with tasks, such as restoration, trail work, cleanup, and noxious weed control. The group will have a cook and a leader who handles logistics. Recreation days are part of each trip.

Agency expectations and costs: Free to the agency, although if funding is adequate, a stipend for volunteers is appreciated. The agency directs the work, provides tools, and provides support to pack food, tools, and gear (participants carry their own personal gear).

Cost to volunteers: Varies by project, ranging from $375 to $500, plus transportation. Food is included in the cost.

Student Conservation Association (SCA)
689 River Rd.
P.O. Box 550
Charlestown, NH 03603–0550
Phone: 603–543–1700
Web site: *http://www.thesca.org*
E-mail: *rauger@thesca.org*

Types of volunteer offerings: Three basic program offerings have a variety of options with a variety of costs.

- SCA Conservation Internships—College students and other adults can volunteer for 12 weeks, 6 months, or 2 years to perform most types of resource management work, including wilderness restoration.

Agency expectations and costs: A 12-week internship costs the agency about $2,400. This cost varies, depending on transportation, uniform needs, and other incidental costs. The agency provides housing, training, supervision, gear, tools, and so forth.

Cost to volunteers: Volunteers receive a stipend of $50 per week for food and incidentals from the SCA and reimbursement of transportation and uniform costs. Students who complete their program may be eligible for an Americorps education grant.

- SCA Diversity Internships—This program is similar to the conservation internships, but actively recruits persons of color and women. A 12-week internship costs the agency about $3,175.
- SCA Conservation Crews—A high school work crew (figure 4–4) of six to eight students is supervised by two paid highly trained crewleaders. They live at the project site for 21 to 30 days, including a recreational trip (usually a backpacking trip) at the end of their study.

Figure 4–4—An impromptu team-building exercise for a Student Conservation Association high school work crew.

Agency expectations and costs: Costs vary, based on the crew size and the length of the assignment. For example, a two-leader, six-person crew costs $17,615 for 30 days. The agency provides assistance with transportation from the airport, a place to camp the first night, transportation of gear to and from work locations, tools, two-way radios, a food resupply, and periodic contact to coordinate with leaders, bring in mail, and interact with participants.

Cost to volunteers: Transportation (financial aid is available).

Wilderness Volunteers
P.O. Box 22292
Flagstaff, AZ 86002–2292
Phone: 928–556–0038
Web site: *http://www.wildernessvolunteers.org*
E-mail: *info@wildernessvolunteers.org*

Types of volunteer offerings: Generally, week-long trips with a focus on wilderness work, including restoration projects.

The a**gency expectations and costs**: No cost to the agency. The agency directs the work and provides the tools.

Cost to volunteers: Varies by trip, about $200 for a 7- to 10-day trip, plus transportation.

4.1.6 Using Professional Services

A variety of professional services are available to help you accomplish your restoration project goals. This section discusses potential resources beyond those of your team, including additional Forest Service expertise, skilled help available from other agencies or organizations, and contractors.

4.1.7 Learning From Others

Network to find out who has experience with restoration projects in environments similar to your own. If you can, find out the types of restoration prescriptions that work for them and the methods they use to propagate plants and plant them successfully. Visit their projects. Potential contacts include other Forest Service wilderness managers, employees of other agencies, such as the National Park Service or Bureau of Land Management, university professors, and research scientists. You may wish to consult with agency specialists who are not assigned to your team, such as a geneticist or fire rehabilitation specialist.

Contact managers of restoration projects in similar environments where native species may have been used to restore lands at ski areas, road projects, or visitor centers. Contractors and consultants are a potential source of information, but be sensitive in pressing for their trade secrets!

The Society for Ecological Restoration can steer you to members who live in your area. Your local native plant society can put you in touch with restorationists. A local native plant gardener could provide beneficial information. A list of helpful organizations, along with their Web sites, is included in chapter 5, *Tools of the Trade and Other Resources*.

4.2 Options for Growing Plants

Very few Forest Service units have direct access to a greenhouse facility for propagating native plants. Fortunately, you have a number of options for working with professional growers. Don't be surprised if growers have not worked directly with your selected plant species—many wilderness areas are in environments very different from those with which they are familiar. Your grower may be learning by trial and error.

Supply the grower with any known propagation methods for your species. Explain your goals for genetic diversity, including any specific practice you prefer, such as not overcleaning seed, using all plants produced (without selecting just the superior plants), seed storage, and careful greenhouse management.

4.2.1 Forest Service Nurseries

Forest Service nurseries (figure 4–5) are diversifying their programs to include propagation of plant species other than trees. Discuss your project needs in advance because your project will not be the equivalent of a tree-planting

Figure 4–5—Forest Service nurseries have been producing a variety of native plant species in response to increasing demand.

operation. For example, dormant bareroot stock seedlings are planted in the spring, so Forest Service nurseries might want to deliver your plants at this time. Most subalpine or alpine restoration projects are more likely to be successful if they are completed in the fall right before the seasonal rain and snows.

4.2.2 Plant Material Centers

The Natural Resources Conservation Service has plant material centers located regionally. These centers are staffed by professionals who grow a wide array of native plants for restoration and reclamation projects. Their mission is to produce protocols for large-scale production. Normally, they do not grow plants for small applications, but in some locations they have been working with national parks to provide plants. Talk to other agency restorationists in your area to see if they have worked successfully with the plant material centers.

4.2.3 Other Agency Nurseries

Sometimes, other agencies have greenhouses (figure 4–6) and are happy to help grow plants. If you have a national park near your unit, see if it has a greenhouse. If it does, you may benefit not only from use of the greenhouse, but from networking with other restoration professionals.

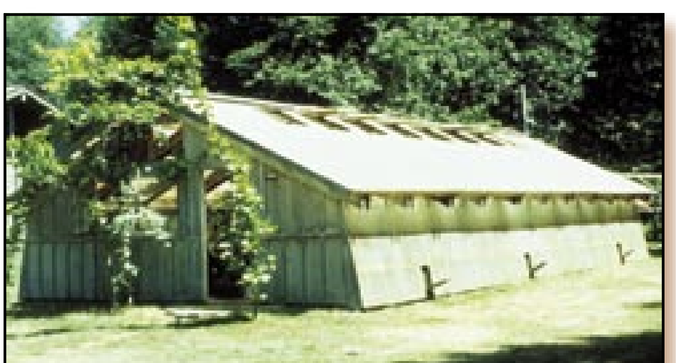


Figure 4–6—Many national parks, such as North Cascades National Park, WA, have greenhouses with plant propagation staff. Park employees are a terrific source of expertise and sometimes are able to help out other agencies.

4.2.4 Contract Growers

Fortunately for restorationists, native plant nurseries are on the rise. Check to see if one is near you. Local nurseries may already have experience in working with your selected species. Often, a local grower is willing to experiment with propagating a small batch of plants at no charge to develop a successful propagation protocol. A restoration project may be the beginning of a long-term working relationship.

4.2.5 School Horticulture Programs

Many high schools (figure 4–7) and colleges have horticulture programs. They might consider becoming partners on your project at a cost savings to you. You may

Figure 4–7—After spending the better part of the school year propagating many flats of plants for 1 hour a day, this high school student was able to take part in the planting at Lake Mary in the Alpine Lakes Wilderness, WA.

only need to pay the cost of materials. Or the plants may cost slightly less than those grown commercially. Make sure an experienced teacher is supervising the project and that your goals for management of the plants are clear. Crop failures may be more likely when plants are grown in an instructional setting because of the lack of adult skills and conflicts with band field trips, spring break, and so forth. You might not end up with all the species and the genetic diversity that you planned for in your planting design. An advantage of this option is that it can create a wonderful learning opportunity for students.

4.2.6 Working With Contractors

Working with contractors can be an excellent means to accomplish all or part of a wilderness restoration project. Many contract restorationists can bring a wealth of expertise to your project.

This section will cover some general principles of contracting (Potash and Aubry 1997; St. John 1995). Check with your contracting officer or other units that use restoration contractors to obtain a sample contract so that you don't have to write one from scratch.

To find reliable contractors, check with sources, such as the Society for Ecological Restoration, local or regional native plant nurseries, your native plant society, other units with restoration projects, and your botanist. You can contract all or part of the project: project planning and design, seed and plant material collection, plant propagation, project implementation and outplanting, site maintenance, and monitoring. For instance, wilderness programs might contract for plant propagation, using a mix of project crews and volunteer labor to implement the project.

4.2.7 General Principles for Successful Contracting

Acquaint yourself with agency contracting guidelines. Each agency has strict procedures that must be followed, including the method of contracting (depending on the amount to be awarded), cutoff dates for submitting requests, and lists of interested contractors that must be notified of bid solicitations.

Work with your contracting office to make definitions, bid items, and other clauses as specific as possible. If items are vague, contractors automatically inflate their bids, raising project costs. In addition, bid-item contracts usually will generate lower bids than lump-sum contracts because the contractor will get paid for each component successfully completed. If your project is in wilderness or a remote setting, be clear about the difficulty of access and potential limitations on the types of tools, such as motorized tools or wheelbarrows. Most professional restorationists do not deal with small hand projects; they are accustomed to using large pieces of machinery (figure 4–8) to treat many acres.

Figure 4–8—Most contractors are accustomed to accomplishing their work with dozers, rippers, imprinters, tractors with drills, and water tenders.

Develop standards for weed control, pathogen and insect control, watering, and signs. Provide a format or forms for project documentation.

Address the things that might go wrong. Provide contingencies for propagation losses, late plant deliveries, bad seed lots, and natural disasters. Plan for ways to handle excess plant materials that may be propagated—perhaps you will opt to buy up an agreed amount of plants and allow the contractor to sell the rest.

Develop your own cost estimates for each bid item. Reject the low bid if it is unrealistically low to deliver the desired result.

Include qualifications for contractors and their personnel to assure project success; qualifications may require previous experience in working with your plant species and in your environment. You may consider preparing a small contract, such as a procurement contract (for less than $2,500), to help a local contractor develop skills in working with your plant species and in your environment.

Performance standards need to be developed to measure success for each bid item. Put yourself in the contractor's shoes—you want your project to succeed, but if your standards are too stringent, you will drive your costs up or create an adverse situation for contract administration. Do your homework—ask other units what type of success can be expected during various stages of your project. For example, if a plant species is difficult to work with, you cannot expect a high rate of survival once seedlings are outplanted.

Sometimes the contract includes remedial measures. For example, if monitoring performed up to 2 years later reveals certain deficiencies in project installation, a contractor can be required to fix it. This can include replanting. If you forced the contractor to follow poor techniques, the failure may not be the contractor's fault.

Build checkpoints into your contract to assure that work is progressing as planned. Careful oversight by an inspector will prevent shoddy work. Adjustments can be negotiated along the way if needed, especially if difficulties arise in working with certain plants. Payments should be made at specified checkpoints, with a portion of the payment saved until the end to assure quality work.

Once a contract is awarded, you will have a prework meeting. If the contractor will be working in the field, be sure to express your expectations for the practice of *Leave No Trace* principles, adherence to wilderness regulations, and campsite locations. Contractors may think they are exempt from pertinent regulations such as restrictions on bringing dogs into the area, having an oversize group, living on public land, or having a campfire. Be sure to discuss any exceptions to regulations in advance and work out potential problems.

Chapter 5

Tools of the Trade and Other Resources

No matter what the job, proper tools will make it easier. Restoration in wilderness settings requires a number of specialized tools (figures 5–1a and 5–1b). This chapter includes information about sources of tools that can make your job easier.

Figures 5–1a and 1b—Restoration workers (top) in the Eagle Cap Wilderness, OR, with the tools and supplies (bottom) they packed into the wilderness.

5.1 Software

- **Biodraw**—Autocad drawings for bioengineering techniques. Geared toward large-scale applications rather than smaller applications used in wilderness and backcountry. Useful for creating technical drawings for contracts. Also includes best management practices and color photos of installations.
- **Erosiondraw**—Similar to Biodraw, but focuses on stabilization techniques that do not rely on living material. Geared toward large-scale applications such as road cutbanks.

Salix Applied Earthcare
225 Locust St., Suite 203
Redding, CA 96001
Phone: 800–403–0474
Web site: *http://www.biodraw.com/*

- **Flora ID Northwest**—This software is an electronic dichotomous key. Choose between Statewide keys, a Pacific Northwest key, and a Great Plains key.

XIDServices, Inc.
P.O. Box 272
Pullman, WA 99163
Phone: 800–872–2943
Web site: *http://www.xidservices.com*

5.2 Government Web Sites

- **Aldo Leopold Wilderness Research Institute**—Wilderness research, including restoration of small disturbed sites. Web site: *http://www.leopold.wilderness.net*
- **Arthur Carhart National Wilderness Training Center**—Offers courses and other tools for wilderness management. Web site: *http://www.carhart.wilderness.net*

- **Colorado Natural Areas Program**—Download the *Native Plant Revegetation Guide for Colorado*. Web site: *http://parks.state.co.us/cnap/revegetation_guide/reveg_index.html*
- **Conservation Plant Materials Centers**—These centers, a service of the Natural Resources Conservation Service, develop protocols for large-scale production of native species for conservation. In recent years, they have worked with the National Park Service to produce plant materials for restoration projects. The specialists who respond to inquiries are very helpful. Web site: *http://www.plant-materials.nrcs.usda.gov/* (Select site map for a list of the centers.)
- **Fire Effects Information System**—Among its various features, this database allows a species-specific search. Web site: *http://www.fs.fed.us/database/feis/*
- **National Plants Database**—Helpful Web site that includes plant life histories (native species and introduced weeds), species distribution maps, and the most current scientific names as well as previous scientific names. Web site: *http://plants.usda.gov/*
- **Soil Quality Institute**—This Natural Resources Conservation Service Web site has helpful publications for assessing and managing rangeland soils available online. Web site: *http://soils.usda.gov/sqi/*
- **University of Montana Invader Database**—Noxious weed database for a five-State area. Web site: *http://invader.dbs.umt.edu/*

5.3 Organizational Web Sites

- **Erosion Control**—Back issues of journal articles are available online. Web site: *http://www.forester.net/ec.html*
- **Native Plant Journal**—Excellent online database with plant propagation protocols. The journal features various native plant species. Web site: *http://www.nativeplantnetwork.org/*
- **Native Plant Societies**—Many of these Web sites have links to additional resources. Consider joining your State's native plant society to learn about native plant communities.
  Arizona—*http://www.aznps.org/* (this site has links to all States)
  California—*http://www.cnps.org/*
  Colorado—*http://www.conps.org/conps.html*
  Idaho—*http://www.idahonativeplants.org/default.aspx*
  Montana—*http://www.umt.edu/mnps/*
  New Mexico—*http://npsnm.unm.edu/*
  Nevada—*http://heritage.nv.gov/nnps.htm*
  Oregon—*http://www.npsoregon.org/*
  Utah—*http://www.unps.org/*
  Washington—*http://www.wnps.org/*
  Wyoming—*http://www.rmh.uwyo.edu/wnps.html*
- **Natural Areas Association**—Publishes the Natural Areas Journal, which includes many articles on restoration. Web site: *http://www.naturalarea.org/*
- **Society for Ecological Restoration (SER)**—This Web site has lots of useful information including the *Primer of Ecological Restoration*. SER publishes two restoration journals, hosts conferences both internationally and regionally, and is working with Island Press Books to produce a series of books on ecological restoration. Web site: *http://www.ser.org/*

5.4 Restoration Tools and Products

For a more complete listing of potential restoration tools and supplies see *Items To Consider Including in a Restoration Project Budget* in section 4.1.2, *Budgeting.* Most tools and products mentioned in this guide are available through forestry, agriculture, greenhouse, or gardening supply distributors. Several mail-order suppliers are listed below, but you may find a supplier in your area who can help you save on shipping costs.

- **Forestry Suppliers, Inc.**

P.O. Box 8397
205 West Rankin St.
Jackson, MS 39284-8397
Phone: 800–752–8460 (customer service); 800–430–5566 (technical support)
Web site: *http://www.forestry-suppliers.com/*

- **IFM** (Integrated Fertility Management, an organic growing supplier)

1422 N. Miller St., No. 8
Wenatchee, WA 98801
Phone: 800–332–3179
Web site: *http://www.agecology.com/*

- **Steuber Distributing Co.** (greenhouse and nursery wholesaler)

P.O. Box 100
Snohomish, WA 98291–0100
Phone: 800–426–8815 (continental U.S.)
Web site: *http://www.steuberdistributing.com/*

5.4.1 Pick Hoes or Miniature Plowshares

Fine garden supply companies are the most likely sources for these tools. Pick hoes (see figure 3–130) are the best tools for planting small greenhouse transplants. Unlike trowels, they use the power of the arm and shoulder, not just the hand, and keep the wrist in a more neutral position.

- **E-Z Digger Oriental Garden Tool** (Item 52604)

Lehman's
One Lehman Circle
P.O. Box 321
Kidron, OH 44636
Phone: 888–438–5346
Web site: *http://www.lehmans.com/*

- **Long-Handled Ho-Mi Digger** (Item CB103)

Lee Valley Tools, Ltd.
P.O. Box 1780
Ogdensburg, NY 13669–6780
Phone: 800–871–8158
Web site: *http://www.leevalley.com/*

- **Hoematic Pick and Digger** (Item 627050)

Aubuchon Hardware
95 Aubuchon Dr.
Westminster, MA 01473
Phone: 800–431–2712
Web site: *http://aubuchonhardware.com/*

- **Pick & Hoe** (Item G-2107)

Hidatool, Inc.
1333 San Pablo Ave.
Berkeley, CA 94702
Phone: 800–443–5512 or 510–524–3700
Web site: *http://www.hidatool.com/*

5.4.2 U-Bar Diggers

This tool (see figure 3–27) breaks up compaction to a depth of a foot (300 millimeters) or more. It will even pierce a hard plow-pan layer, but doesn't work well when compaction is at the soil surface. Push the tool's prongs in the soil, step onto the crosspiece, then use the handles to rock the tool back and forth gently (see section 2.3a, *Scarification*). This tool saves much backbreaking work that would otherwise require a pick or shovel. If you use stock to transport a U-bar digger, cover the tool's sharp tines with a homemade scabbard (figure 5–2).

Figures 5–2—When transporting a U-bar digger using stock, cover the tool's sharp tines with a homemade scabbard.

- **U-Bar Digger** (Item LB101)
Lee Valley Tools, Ltd.
P.O. Box 1780
Ogdensburg, NY 13669–6780
Phone: 800–871–8158
Web site: *http://www.leevalley.com/*

5.4.3 Balanced Watering Cans

The French watering can refers to a handle design that arches all the way from the base of the watering can up to the top front near the spout (see figure 3–140a). This design is easier on the back and arms because it allows the user to balance the can easily as it is tilted back and forth. Workers can carry full watering cans in pairs to balance the weight on both sides of their body. If you find this style of watering can at your local garden store, buy a supply, as they are hard to find in lightweight plastic.

- **French Blue Watering Can** (Item 06-341)
Gardener's Supply Co.
28 Intervale Rd.
Burlington, VT 05401
Phone: 888–833–1412
Web site: *http://www.gardeners.com/*

5.4.4 Systemic Repellants

A repellant treatment lasts for about 3 months after planting. There are formulations for deer and rodents (gophers and mice). The repellant is expensive, but not as expensive as replacing plantings.

- **Repellex**
Repellex Seedling Protection Systems
1888 Bobblett St.
Blaine, WA 98230
Phone: 877–737–3548
Web site: *http://www.repellex.com*

5.4.5 Restoration Signs

This Polydura 19 sign (see figure 3–142b) can be attached to a stake or hung from cord to close restoration sites.

- **Restoration Sign** (Item P1479)
J.L. Darling Corp.
2614 Pacific Hwy. East
Tacoma, WA 98424
Phone: 253–922–5000
Web site: *http://www.riteintherain.com/*

5.4.6 Erosion-Control Blankets

A variety of erosion-control blankets are on the market. Each company will probably refer you to a regional distributor. Prices vary by area. The products included here are all degradable—a desirable attribute for wilderness and backcountry applications. Nettings are photodegradable over a period of years; the knots of the net are the last to degrade and can remain for many years. Small animals can become entangled in any netting product. With many products, the netting is loose and can be removed when the product is installed. Nondegradable geotextile products are also on the market. They may be needed to stabilize the soil in extreme situations. Straw and excelsior products are very bright when first installed, but they turn gray in a season or two. Compare figures 3–138a and 138b (new Curlex and Curlex after one winter) with figure 3–147d (Curlex years after installation).

American Excelsior Co.
850 Ave. H East
Arlington, TX 76011
Phone: 800–777–7645
Web site: *http://www.curlex.com*

Product: Curlex I

Width ft (m)	Length ft (m)	Area covered sq ft (sq m)	Weight lb (kg)	Cost per roll (dollars)
8 (2.4)	101.25 (30.8)	810 (75.25)	66 (30)	40

Description: Aspen wood shavings with photodegradable plastic mesh (see figure 3–147b). Natural-colored netting on one side of the blanket. Available with white photodegradable netting that decomposes in 30 to 60 days.

Advantages: Easy to install, promotes seedling survival, decomposes in 2 to 5 years. Proven to work well in subalpine environments. Netting can be removed.

Disadvantages: Another blanket application may be needed every 3 to 4 years if the site has not stabilized adequately.

Product: Curlex III

Width ft (m)	Length ft (m)	Area covered sq ft (sq m)	Weight lb (kg)	Cost per roll (dollars)
8 (2.4)	67.5 (20.6)	540 (50.2)	75 (34)	54

Description: Aspen wood shavings with black heavy-duty plastic netting on both sides. Available with biodegradable woven jute thread.

Advantages: Effective on steep slopes and areas with high-velocity runoff.

Disadvantages: Netting is visible and lasts for many years.

Product: Curlex NetFree

Width ft (m)	Length ft (m)	Area covered sq ft (sq m)	Weight lb (kg)	Cost per roll (dollars)
8 (2.4)	90 (27.4)	720 (67)	58 (26)	44

Description: Aspen wood shavings with 100-percent biodegradable stitching.

Advantages: Protects seeds, enhances germination, and hastens revegetation. No netting to ensnare animals. Attaches to soil surface with biodegradable plastic staples.

Disadvantages: Too new to evaluate.

Contech Construction Products, Inc.
9025 Centre Pointe Drive, Suite 400
West Chester, OH 45069
Phone: 800–338–1122
Web site: *http://www.contech-cpi.com*

Product: C-Jute

Width ft (m)	Length ft (m)	Area covered sq ft (sq m)	Weight lb (kg)	Cost per roll (dollars)
12.5 (3.8)	432 (132)	5,400 (502)	90 (41)	300

Description: Lightweight biodegradable green synthetic jute.

Advantages: Holds seed and soil in place. Allows unobstructed growth of woody material. Degrades in 12 months.

Disadvantages: Doesn't control erosion as well as denser products. Breaks down too quickly to be useful for many restoration projects. Highly flammable.

Product: SFB1

Width ft (m)	Length ft (m)	Area covered sq ft (sq m)	Weight lb (kg)	Cost per roll (dollars)
7.5 (2.3)	120 (37)	900 (84)	40 (18)	50

Description: Straw blanket with yellow netting on one side.

Advantages: Protects slopes as steep as 3:1. Degrades in 12 months.

Disadvantages: Some risk of importing weed seed.

Product: SFB2

Width ft (m)	Length ft (m)	Area covered sq ft (sq m)	Weight lb (kg)	Cost per roll (dollars)
7.5 (2.3)	120 (37)	900 (84)	40 (18)	60

Description: Straw blanket with yellow netting on both sides.

Advantages: Good for slopes as steep as 3:1. Degrades in 18 months.

Disadvantages: Some risk of importing weed seed.

Product: SCFB2

Width ft (m)	Length ft (m)	Area covered sq ft (sq m)	Weight lb (kg)	Cost per roll (dollars)
7.5 (2.3)	120 (37)	900 (84)	40 (18)	65

Description: Straw/coconut blend blanket.

Advantages: Good for slopes as steep as 2:1. Degrades in 24 months.

Disadvantages: Some risk of importing weed seed.

Product: CFB2

Width ft (m)	Length ft (m)	Area covered sq ft (sq m)	Weight lb (kg)	Cost per roll (dollars)
7.5 (2.3)	120 (37)	900 (84)	46 (21)	110

Description: 100-percent coconut blanket with tan biodegradable netting.

Advantages: Good for slopes as steep as 2:1 and for protecting channels. Degrades in 48 months.

Disadvantages: Does not work as well as excelsior products for retaining moisture and preventing soil recompaction in subalpine settings.

Erosion-Control Systems
9015 Energy Lane
North Port, AL 35476
Phone: 205–373–8900

Product: ProGuard-SS

Width ft (m)	Length ft (m)	Area covered sq ft (sq m)	Weight lb (kg)	Cost per roll (dollars)
8 (2.4)	112 (34)	900 (84)	55 (25)	25

Description: Agricultural straw with photodegradable plastic netting on one side, sewn on 2-inch (51-millimeter) centers.

Advantages: Lightweight, encourages growth for 6 to 8 months. Available in custom widths.

Disadvantages: May decompose too quickly. Some risk of introducing weed seed. The 8-foot-wide rolls would have to be cut in half before they could be packed by stock.

Product: Proguard-DS

Width ft (m)	Length ft (m)	Area covered sq ft (sq m)	Weight lb (kg)	Cost per roll (dollars)
8 (2.4)	112 (34)	900 (84)	60 (27)	28

Description: Agricultural straw with photodegradable plastic netting on both sides, sewn on 2-inch (51-millimeter) centers.

Advantages: Encourages growth for 6 to 8 months in areas with medium runoff and on slopes from 2:1 to 3:1. Available in custom widths.

Disadvantages: May decompose too quickly. Some risk of introducing weed seed. The 8-foot-wide rolls would have to be cut in half before they could be packed by stock.

Product: Everhold XL1 (Excelsior blanket)

Width ft (m)	Length ft (m)	Area covered sq ft (sq m)	Weight lb (kg)	Cost per roll (dollars)
8 (2.4)	112 (34)	900 (84)	85 (39)	35

Description: Excelsior fiber mat covered with photodegradable plastic netting, sewn on 2-inch (51-millimeter) centers.

Advantages: Provides erosion maintenance for 6 to 12 months. Promotes seedling survival. May be easier to install than Curlex.

Disadvantages: The 8-foot-wide rolls would have to be cut in half before they could be packed by stock.

Product: Everhold XL3 (High-impact excelsior blanket)

Width ft (m)	Length ft (m)	Area covered sq ft (sq m)	Weight lb (kg)	Cost per roll (dollars)
8 (2.4)	112 (34)	900 (84)	120 (54)	45

Description: Wood excelsior with photodegradable plastic netting, sewn on both sides.

Advantages: Erosion control for 12 to 24 months. Good for areas with high erosion potential.

Disadvantages: Heavy. The 8-foot-wide rolls would have to be cut in half before they could be packed by stock.

Product: DuraGuard C1 (Coconut blanket)

Width ft (m)	Length ft (m)	Area covered sq ft (sq m)	Weight lb (kg)	Cost per roll (dollars)
8 (2.4)	112 (34)	900 (84)	95 (43)	62

Description: Durable coconut fibers encased in heavyweight UV-stabilized nets on both sides.

Advantages: Erosion control for up to 3 years. Good for slopes as steep as 1:1 and areas with high runoff. Dark brown color blends in faster on dark soils (see figure 3–139a). Other products need a couple years to weather before blending in. Easy to install.

Disadvantages: Doesn't work as well as excelsior products for retaining soil moisture and preventing soil recompaction in subalpine settings. The 8-foot-wide rolls would have to be cut in half before they could be packed by stock.

Product: DuraBlend SC1 (Straw/coconut blanket)

Width ft (m)	Length ft (m)	Area covered sq ft (sq m)	Weight lb (kg)	Cost per roll (dollars)
8 (2.4)	112 (34)	900 (84)	65 (29)	54

Description: Straw and coconut fibers that will degrade more slowly, sewn with photodegradable plastic netting on both sides.

Advantages: Erosion control for up to 3 years. Good for slopes as steep as 2:1 and areas with medium runoff.

Disadvantages: Some risk of importing weed seed. The 8-foot-wide rolls would have to be cut in half before they could be packed by stock.

North American Green
14649 Hwy. 41 North
Evansville, IN 47725
Phone: 800–772–2040
Web site: *http://www.nagreen.com*

Product: DS150 (Straw blanket)

Width ft (m)	Length ft (m)	Area covered sq ft (sq m)	Weight lb (kg)	Cost per roll (dollars)
6.7 (2)	108 (33)	720 (67)	40 (18)	50

Description: Straw fiber blanket with photodegradable netting on both sides.

Advantages: Erosion control for up to 2 months. Lightweight. Stitched every 1 1/2 inches (38 millimeters).

Disadvantages: Netting may decompose too quickly. Some risk of importing weed seed.

Product: S150 (Straw blanket)

Width ft (m)	Length ft (m)	Area covered sq ft (sq m)	Weight lb (kg)	Cost per roll (dollars)
6.7 (2)	108 (33)	720 (67)	40 (18)	50

Description: Straw blanket with photodegradable netting on both sides.

Advantages: Erosion control for up to 12 months on 2:1 to 3:1 slopes and in areas with drainage channels carrying moderate flows.

Disadvantages: Decomposes rapidly. Some risk of importing weed seed.

Product: S75 (Straw blanket)

S75BN 100-percent biodegradable natural netting

Width ft (m)	Length ft (m)	Area covered sq ft (sq m)	Weight lb (kg)	Cost per roll (dollars)
6.7 (2)	108 (33)	720 (67)	40 (18)	40

Description: Straw blanket with photodegradable netting on one side.

Advantages: Erosion control for up to 12 months. Promotes seedling survival on 3:1 to 4:1 slopes.

Disadvantages: Some risk of importing weed seed.

Product: SC150 (Straw/coconut blanket)

Width ft (m)	Length ft (m)	Area covered sq ft (sq m)	Weight lb (kg)	Cost per roll (dollars)
6.7 (2)	108 (33)	720 (67)	44 (20)	70

Description: 70-percent straw/30-percent coconut fiber blanket with netting on both sides.

Advantages: Erosion control for up to 24 months. Provides long-term erosion control and allows vegetation to become established on slopes as steep as 1:1 and in areas with drainage channels carrying moderate flows.

Disadvantages: Some risk of importing weed seed.

Product: C125BN (Coconut blanket)

Width ft (m)	Length ft (m)	Area covered sq ft (sq m)	Weight lb (kg)	Cost per roll (dollars)
6.7 (2)	108 (33)	720 (67)	52 (24)	70

Description: 100-percent coconut fiber blanket with biodegradable natural netting on both sides.

Advantages: Erosion control for up to 24 months. Provides long-term erosion control and allows vegetation to become established on slopes steeper than 1:1 and in areas with drainage channels carrying high flows.

Disadvantages: Does not work as well as excelsior products for retaining soil moisture and preventing recompaction in subalpine settings.

Mirafi Construction Products

365 South Holland Dr.
Pendergrass, GA 30567
Phone: 706–693–2226
Web Site: *http://www.mirafi.com*

Product: Miramat TM8 blanket

Width ft (m)	Length ft (m)	Area covered sq ft (sq m)	Weight lb (kg)	Cost per roll (dollars)
12 (3.7)	100 (30)	1,197 (111)	100 (45)	Call for estimate

Description: An ultraviolet-stabilized polypropylene rolled mat created for revegetation and to reinforce turf.

Advantages: Highly porous, very flexible. Enhances vegetative growth.

Disadvantages: Heavy, takes a long time to degrade. Would need to be cut before it could be packed by stock.

Propex Fabrics, Inc.

6025 Lee Hwy.
Chattanooga, TN 37421
Phone: 800–445–7732
Web site: *http://www.geotextile.com*

Product: Landlok SuperGro

Width ft (m)	Length ft (m)	Area covered sq ft (sq m)	Weight lb (kg)	Cost per roll (dollars)
7.5 (2.2)	1,200 (366)	9,000 (836)	44 (20)	450

Description: Flexible, scrim composite blanket of polypropylene fibers reinforced with polypropylene netting. Good for slopes up to 1.5:1 and for areas with heavy rainfall.

Advantages: Lightweight, conforms to the surface of the ground, and promotes absorption of water by the soil. Fibers mimic root structure. Applying water on the product's surface helps it adhere to the soil.

Disadvantages: Netting degrades in about 2 months, which may be too soon for some restoration sites.

Product: Landlok S2

Width ft (m)	Length ft (m)	Area covered sq ft (sq m)	Weight lb (kg)	Cost per roll (dollars)
8 (2.45)	112.5 (34.3)	900 (84)	53 (24)	Call for estimate

Description: Wheat straw blanket with photodegradable netting on both sides, stitched on 2-inch (51-millimeter) centers.

Advantages: Degrades in 12 months.

Disadvantages: Some risk of importing weed seed. The stitched netting cannot be removed.

Product: Landlok C2

Width ft (m)	Length ft (m)	Area covered sq ft (sq m)	Weight lb (kg)	Cost per roll (dollars)
8 (2.45)	112.5 (34.3)	900 (84)	55 (25)	Call for estimate

Description: 100-percent coconut fiber blanket with photodegradable netting on both sides, stitched on 2-inch (51-millimeter) centers.

Advantages: Degrades in 36 months.

Disadvantages: Does not work as well as excelsior products for retaining soil moisture and preventing soil recompaction in subalpine settings. The stitched netting cannot be removed.

Product: Landlok S1

Width ft (m)	Length ft (m)	Area covered sq ft (sq m)	Weight lb (kg)	Cost per roll (dollars)
8 (2.45)	112.5 (34.3)	900 (84)	53 (24)	Call for estimate

Description: 100-percent wheat straw with photodegradable netting on one side, stitched on 2-inch (51-millimeter) centers.

Advantages: Degrades in 12 months.

Disadvantages: Some risk of importing weed seed. The stitched netting cannot be removed.

Product: Landlok CS2

Width ft (m)	Length ft (m)	Area covered sq ft (sq m)	Weight lb (kg)	Cost per roll (dollars)
8 (2.45)	112.5 (34.3)	900 (84)	55 (25)	Call for estimate

Description: 70-percent wheat straw/30-percent coconut fiber. The top netting is UV-stabilized polypropylene. The bottom netting is photodegradable polypropylene. Mesh openings are 3/8 by 3/8 inch (9.5 by 9.5 millimeters).

Advantages: Degrades in 24 months.

Disadvantages: Some risk of importing weed seed.

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Photo courtesy of the Steve Slocomb.

Appendixes

Appendix A—Treatments To Manage Factors Limiting Restoration

Limiting factor	Potential treatments to compensate	Potential plant types or propagation methods
Extreme heat	Add mulch. Install vertical mulch. Install shade cards.	Favor species with adaptations to survive heat, such as thick or waxy cuticles, light surfaces, etc. Make sure transplants have a high root-to-shoot ratio. Use 1-1 or plug-1 stock.
Extreme cold	Add mulch. Use perforated plastic landscape film to induce germination or protect seedlings.	Favor species with adaptations to survive cold, such as thick or waxy cuticles. Transplant wildlings. Transplant greenhouse-grown plants that are past the tender seedling stage.
Wind or sand blast	Install vertical mulch. Install shade cards. Spray antidesiccant on foliage. Pit and imprint the soil.	Favor species with adaptations to survive cold, such as thick or waxy cuticles. Transplant wildlings. Transplant greenhouse-grown plants that are past the tender seedling stage.
Herbivory	Install wire cages. Install tree tubes. Use repellants. Install row cover. Wrap the stems. Limit watering.	Favor plants that are poisonous, have spines, or are not palatable. Cut back on fertilizing before outplanting greenhouse stock. Make sure transplants have a high root-to-shoot ratio. Use 1-1 or plug-1 stock.
Granivory	Spread cracked wheat before seeding.	
Frost heave or needle ice	Add mulch. Tamp soil firmly around plants when planting. Pit and imprint the soil.	

Limiting factor	Potential treatments to compensate	Potential plant types or propagation methods
Short growing season	Use plastic film to enhance germination and seedling growth.	Transplant wildlings. Transplant greenhouse-grown stock.
Lack of soil moisture	Sow seed at the onset of the rainy season. Ensure firm seed-to-soil contact. Reduce compaction with scarification. Pit and imprint the soil. Avoid working the soil when it is excessively wet or dry. Water when planting. Water by hand or install an irrigation system. Use buried clay-pot irrigation. Increase organic material in the soil or use other soil amendments. Inoculate the soil with micro-organisms. Add mulch.	Favor species with adaptations to survive drought, such as those with thick or waxy cuticles, spines, reflective or hairy surfaces, high root-to-shoot ratios, or the ability to drop leaves when stressed. Transplant greenhouse-grown stock raised in deep containers.
Poor water infiltration	See *Increased Soil Compaction* below. Manage physical crust formation after vegetation is reintroduced.	See *Increased Soil Compaction* below.
Lack of precipitation for germination or seedling establishment	Irrigate seeded areas.	Transplant wildlings. Reseed if necessary. Transplant greenhouse-grown stock.
Sun intolerance	Install shade cards. Install vertical mulch. Pit and imprint the soil.	Select plants that are growing in full sun. Plant in cooler or cloudier times of year. Harden off before planting.

Limiting factor	Potential treatments to compensate	Potential plant types or propagation methods
		Use B-1 fertilizer to reduce transplant shock. Prune back plants by one-third.
Loss of soil layers	Rebuild soil from onsite sources. Import topsoil. Inoculate with mycorrhizae. Import compost or other soil amendments.	Favor species found growing on sites with similar disturbances.
Inadequate soil nutrients	Add local organic matter. Inoculate with mycorrhizae. Import compost, other soil amendments, or use fertilizer to correct nutrient and pH levels.	Favor species with a high root-to-shoot ratio. Favor species that are nitrogen fixers.
Loss of soil micro-organisms	Rebuild soil from onsite sources. Import topsoil. Inoculate soil when transplanting nursery stock or after seedlings have emerged.	Inoculate greenhouse soil.
Increased soil compaction	Scarify to compacted depth. Increase soil organic matter. Inoculate with mycorrhizae. Reintroduce large soil organisms. Avoid recompaction by: • Minimizing repeated walking or equipment use • Adding mulch Allow for cycles of wetting and drying.	Favor species found growing on similar disturbances. Increase plant cover. Favor species with a variety of root forms (fibrous roots, taproots, spreading roots). Favor plants with lots of root biomass. Avoid plants with dense root mats.

Limiting factor	Potential treatments to compensate	Potential plant types or propagation methods
Physical crust formation (Prevents water infiltration and seedling establishment)	Increase organic matter and break up crust. Add topsoil from the site. Import topsoil. Inoculate with mycorrhizae. Encourage biological crust formation where appropriate. Add mulch.	
Change in soil pH (Soil toxicity)	Add topsoil from the site. Import topsoil. Inoculate with mycorrhizae. Correct with soil amendments. Improve drainage.	Favor species found growing on sites with similar disturbances.
Excess sodium	Apply gypsum and flush with water. Improve drainage.	
Altered slope or drainage	Recontour. Install drainage structures.	Favor species adapted to altered conditions.
Continuing erosion	Avoid use when wet. Prevent further damage to biological soil crusts. Add organic matter. Increase surface residue and roughness. Stabilize with: • Checkdams or siltdams • Soil binders • Erosion control blankets • Bioengineering structures Inoculate with mycorrhizae.	Favor species that will provide cover rapidly. Favor species with a variety of root forms (fibrous roots, taproots, spreading roots). Favor species that lend themselves to propagation with bioengineering techniques.

Limiting factor	Potential treatments to compensate	Potential plant types or propagation methods
Suppression of natural disturbance	Reestablish or emulate natural processes.	Favor species that do not depend on disturbance for survival.
Weed competition	Minimize fertilization, especially with nitrogen. Minimize irrigation. Solarize the soil. Control weeds. Inoculate with mycorrhizae. Add mulch.	Select species that will shade weeds. Select a variety of species to fill in all niches (for instance, shrubs, graminoids, and forbs).
Continued damaging use	Reduce or remove use with: • Physical barriers • Information and education • Regulation and enforcement	Transplant larger plants of species that will deter use, such as larger shrubs, plants with spines or thorns, or poisonous plants. Favor species that are resistant to damage.

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Appendix B—Propagation and Establishment of Requirements for Selected Plant Species

The information displayed for each plant species was gleaned from just a few sources. Additional information is available for these plant species, but this chart should provide a starting point. In the *Propagation Method* column, numbers in **bold** text indicate the method of propagation that the literature suggested would be the most successful. In the *References* column, authors in **bold** text indicate works with more complete descriptions.

Key to Propagation Methods

1. Seed
    a. Cold moist stratification: the number of days required for stratification follows (for example, 1a: 60)
    b. Scarification
    c. Water leaching
    d. Treatment with sulfuric acid
    e. No treatment needed
    f. Warm/cold stratification (days required for warm/cold stratification; for example, 1f: 45/140)
    g. Other
2. Semihardwood stem cuttings
3. Hardwood stem cuttings (firm stems after leaves have dropped)
4. Softwood or herbaceous cuttings
5. Root cuttings
6. Leaf cuttings
7. Leaf bud cuttings
8. Divisions
9. Simple layering
10. Mound layering
11. Trench layering
12. Tip layering
13. Seed-increase program

Scientific name Common name	Propagation method	References	Remarks
Abies spp.	1a: 14–28	Young and Young 1986	Germinates in or on melting snowbanks in the wild.
Abies grandis Grand fir	1a: 15–30	Rose and others 1998	The seed is fragile and requires afterripening in the cone. Do not extract it immediately. Stratify and sow the seed 0.2 inch (5 millimeters) deep during the spring.
Abies lasiocarpa Subalpine fir	1, 2	Weisberg 1993	
Abronia latifolia Yellow sand verbena	1	Schmidt 1980	Direct sow the seed during the fall on sandy soil in full sun. Expect spotty germination. Seedlings do not tolerate disturbance.
Abronia umbellata Pink sand verbena	1	Schmidt 1980	Direct sow the seeds during the fall. Protect the seedlings from moles and rabbits until they have become established.
Abronia villosa Desert sand verbena	1	Schmidt 1980	Annual species. Direct sow the seed on sandy soil during the fall or early spring.
Acer circinatum Vine maple	1a: 120–240 or 1f: 30–60 warm/ 30–90 cold	**Potash and Aubry 1997** Landis and Simonich 1983 **Link 1993** Rose and others 1998	Collect the seed when it is green, from August to October. Stratify the seed immediately or plant the seed on the site. Start the seed during the spring. It takes 3 to 4 months to grow. Bareroot and containerized stock also have been planted successfully.
Acer glabrum Rocky Mountain maple	1f: 180 warm/180 cold	**Link 1993** Rose and others 1998	Apply seed directly on the site. Expect 25-percent germination.
Acer macrophyllum Bigleaf maple	1a: 40–80, 8	Weisberg 1993 **Rose and others 1998**	Seed decays rapidly. Collect seed late in the fall before the rains. Stratify the seed before sowing it at 34 to 41 degrees Fahrenheit (1 to 5 degrees Celsius). Sow during February or early March or plant directly during the fall.

Scientific name Common name	Propagation method	References	Remarks
Achillea millefolium Western yarrow	1, 8 (spring)	Potash and Aubry 1997 **Rose and others 1998** Young and Young 1986	Seed ripens between August 1 and October 31. Cut off the seed heads. Plant seed directly during the fall or late April, or plant 1.6-inch (40-millimeter) rhizome fragments. Lift divisions during the early spring and divide them into small groups of rosettes. Cut back the leaves and plant them.
Achlys triphylla Vanilla leaf	8	Weisberg 1993	
Actaea rubra Baneberry	1, 1a	Schmidt 1980	Remove the seed from pulpy fruit. Add peat or wood humus to the soil before sowing the seed. If germination is poor, cold stratification may help.
Adenocaulon bicolor Trail plant	8	Weisberg 1993	
Adenostoma fasciculatum Chamise	1d	Young and Young 1992	The hard seedcoat requires acid treatment. An alternative is to sow seed in soil in flats and burn pine needles on the surface.
Adenostoma sparsifolium Red shank	1d	Young and Young 1986	Treat seed in sulfuric acid for 15 minutes.
Adiantum spp. Maidenhair fern	8, spores	**Schmidt 1980**	Schmidt (1980) includes the complete protocol for propagating ferns from spores.
Aesculus californica California buckeye	1e	Harris and Leiser 1979	Direct seed during the fall.
Agave utahensis Century plant	1e	**Link 1993**	Grow seedlings in deep-ridged containers with well-drained medium. Fertilize seedlings with each watering.
Agoseris glauca	1	Weisberg 1993	

Scientific name Common name	Propagation method	References	Remarks
Agropyron macrourum	1e, 13	Densmore and others 1990 Young and Young 1986	
Agropyron spicatum Bluebunch wheatgrass	1e	Rose and others 1998	Collect seed during the fall. Remove awns with a hammer mill. Sow a minimum of 100 to 160 seeds per square acre during the fall.
Agrostis scabra Rough bentgrass	1e	**Link 1993**	Seed ripens from July 15 to August 15. Collect seed for a seed-increase program. Broadcast the seed and rake it into the soil.
Ailanthus altissima Tree of heaven	1a: 60	Young and Young 1986	
Allium spp.	1a	Young and Young 1986	
Alnus spp.	1a: 180	Young and Young 1986 Hartmann and others 1990	Thoroughly clean the seed. Sow the seed when it is fresh or chill the seed before planting.
Alnus crispa	1	Densmore and others 1990	This alder fixes nitrogen. Inoculate its seedlings with a solution made from root nodules.
Alnus incana Thinleaf alder	1a: 180, 1e, 4	Rose and others 1998	Collect fruit during the fall when the bracts start to separate. Fresh seed will not stratify. Dried seed stratifies at 41 degrees Fahrenheit (5 degrees Celsius). Sow during the spring.
Alnus rubra Red alder	**1e**, 4	**Potash and Aubry 1997** Rose and others 1998	This alder fixes nitrogen. The seed ripens from September 1 to October 15. Seed from the upper one-third of the tree is more likely to be viable. The seed is ripe when the strobile (a fruiting structure characterized by rows of overlapping scales) twists easily and its scales part. Start seed during the spring or sow onsite during the fall. Seed needs light to germinate. Plants are more likely to become established when they are planted in mineral soil, watered, and supplied with fertilizer that is low in nitrogen and high in phosphorus.

Scientific name Common name	Propagation method	References	Remarks
Alnus sinuata Sitka alder	**1a: 30–90**, 4	**Potash and Aubry 1997** Rose and others 1998	This alder fixes nitrogen. See *Alnus rubra* for instructions on handling seed. Inoculate the planting medium with root nodules.
Amelanchier alnifolia Saskatoon serviceberry	1e or 1a: 112–168, 5, 8	**Rose and others 1998**	Collect seed during the late summer. Macerate fruit with water. The seed has a tendency to develop fungal mold. Plant the seed during the winter or stratify the seed at 34 to 43 degrees Fahrenheit (1 to 6 degrees Celsius) and plant it in sandy soil during the spring. Take root cuttings from December to February. Cut segments of fleshy roots 2 inches (50 millimeters) long. The cut should be horizontal at the end closest to the root crown and slanted at the end farthest from the crown. For reproduction by division, divide plants during the early spring.
Amelanchier utahensis Utah serviceberry	1a: 60 4	**Link 1993**	Seed ripens between April 1 and August 31. Clean seed by macerating fruit and washing the pulp over screens. Dry the pulp, then rub the seed through the screens.
Amorpha californica California false indigo	1e	Young and Young 1992	Soaking seed in hot water for 10 minutes may improve germination.
Amorpha canescens	1e	Young and Young 1992	
Amorpha fruticosa	1e	Young and Young 1992	
Amorpha nana	1e	Young and Young 1992	
Anaphalis margaritacea Pearly-everlasting	1e, 8 (spring or fall)	Potash and Aubry 1997 **Rose and others 1998**	Seed ripens between July 1 and October 31 when the flower's center is dark brown. Collect the entire seed head. The pappus (hairs or bristles attached to an achene) can remain on the seed. Sow seed under a thin layer of soil during the spring. For reproduction by division, replant the divided plants during the spring or fall.
Andromeda polifolia Bog rosemary	1a, **2**	Young and Young 1992	The seed needs prechilling. Winter cuttings can be rooted easily.

Scientific name Common name	Propagation method	References	Remarks
Andropogon gerardii Bluestem	1a: 14	Young and Young 1986	The seed needs light and potassium nitrate (KNO_3) to germinate.
Andropogon hallii	1a: 14	Young and Young 1986	The seed needs light and potassium nitrate (KNO_3) to germinate.
Andropogon virginicus Broomsedge bluestem	1e	**Link 1993**	The seed is very difficult to collect and clean because the very small seed is encased in hairy appendages and the leaf sheath.
Anemone multifida Cutleaf anemone	1e	**Link 1993**	Direct seed.
Anemone occidentalis Western pasqueflower	1a: 30–90	**Link 1993**	The seed ripens between August 1 and 31. Dry the seed in an oven to break off the long, plumose tails. During greenhouse trials, seedlings emerged, but did not survive.
Antennaria alpina Alpine pussytoes	1	Weisberg 1993	
Antennaria corymbosa Pussytoes	8	**Link 1993**	When plants that had been divided were planted above the crown, they died back.
Antennaria microphylla Littleleaf pussytoes	1e	**Link 1993**	The seed ripens between June 15 and July 15. Seed production is low. Use cone-tainers or direct seed.
Antennaria neglecta Field pussytoes	1e	**Link 1993**	The seed ripens between June 15 and July 10. Seed production is low. Use cone-tainers or direct seed.
Aquilegia formosa Red columbine	1e	**Link 1993** Rose and others 1998 Young and Young 1986	The seed ripens between June 1 and August 15. Start seed during the spring or fall in cone-tainers or use direct seeding. Seed needs to be chilled for 3 days before planting or it will not germinate.
Arabis spp. Rock cress	1	Young and Young 1986	Seed requires light and potassium nitrate (KNO_3) to germinate.

Scientific name Common name	Propagation method	References	Remarks
Aralia spp. Ginseng	1a, 1b	Young and Young 1992	May need a period of afterripening and scarification, followed by prechilling.
Arbutus menziesii Pacific madrone	1a: 30–90, 4, 9	Rose and others 1998 Young and Young 1992	Collect berries from October to December. Macerate the berries and separate the seed by drying or flotation. Stratify at 36 to 41 degrees Fahrenheit (2 to 5 degrees Celsius) or stratify naturally outdoors over winter.
Arctostaphylos spp. Manzanita	1d, 1f: 60–120/60–90 Cuttings	Landis and Simonich 1983 **Young and Young 1992**	Scarify the seed in sulfuric acid for 3 to 6 hours. Use warm/cold stratification.
Arctostaphylos columbiana Bristly manzanita	2	Weisberg 1993	
Arctostaphylos nevadensis Pinemat manzanita	1a, 1b, 1d, **3**, **4**	**Link 1993** Rose and others 1998	Use cuttings from 1- or 2-year-old wood. Seed is difficult to germinate.
Arctostaphylos patula Greenleaf manzanita	1a: 90, 1b, **4**	**Rose and others 1998**	Seed ripens from July to September. Macerate the fruit and separate the seed using floatation. Scarify the seed in hot water and stratify the seed at 39 degrees Fahrenheit (4 degrees Celsius) in moist sand. Seed can be sown in coarse soil during the early summer. Keep the seedbed mulched over the winter. Take cuttings from stems with five to six nodes of the current year's growth.
Arctostaphylos uva-ursi Kinnikinnick	1d or 1d then f: 60 warm/60 cold 2, 5	**Potash and Aubry 1997** **Rose and others 1998**	The fruit is ripe when it is red or pink, usually from June 1 to October 15. Collect stem cuttings 2 to 6 inches (50 to 150 millimeters) long during the fall. Collect 3- to 5-inch (75- to 150-millimeter) root cuttings during the fall. Separate the seed by flotation or by grinding when the seed is dry. Establish seedlings on well-drained sandy or gravelly soils.
Arctostaphylos viscida Whiteleaf manzanita	1a, 1b, 9	Rose and others 1998	Plant seed during the late summer. Seed needs heat and mechanical or chemical scarification. Stratify the seed over the winter.

Scientific name Common name	Propagation method	References	Remarks
Aristidia longiseta	1e	Young and Young 1986	
Aristidia purpurea Triple-awned grass	1e	Young and Young 1986	
Arnica spp.	8	Weisberg 1993	
Arnica frigida	1	Densmore and others 1990	
Arnica latifolia Mountain arnica	1	Weisberg 1993	
Arnica sororia Twin arnica	1e	**Link 1993**	Seed ripens between July 15 and 31. Seed production is low. Plant in cone-tainers.
Artemesia arbuscula Low sagebrush	1a: 60	**Link 1993** Young and Young 1992	Seed ripens between October 1 and December 31. Sow in rows and transplant to pots or direct sow the seed under ¼ inch (6 millimeters) of soil and cover with light mulch.
Artemesia frigida Fringed sagebrush	1a: 10, 1d	**Link 1993**	Seed ripens during the fall. Direct sow the seed on top of the soil if the soil is moist. Fringed sagebrush is easy to propagate.
Artemesia ludoviciana Sagewort	1a: 14, 1d	**Link 1993**	Seed ripens between July 15 and October 15. Grow in containers or direct seed. Sagewort is easy to grow.
Artemesia tilesii	1	Densmore and others 1990	
Artemesia tridentata Big sagebrush	1a: 0–10, 3	Landis and Simonich 1983 Rose and others 1998	Seed ripens between November 5 and January 15. Start seedlings during the spring, summer, or fall. Seed takes 2 to 3 months to grow.
Aruncus sylvester Goatsbeard	1, 8 (spring)	Potash and Aubry 1997	Seed ripens between July 1 and November 30. Shake the seed loose or strip the heads. Sow seed during the fall when the soil is moist.

Scientific name Common name	Propagation method	References	Remarks
Asarum caudatum Wild ginger	1, 5, **8**	Weisberg 1993 **Rose and others 1998**	Mature seed is difficult to collect, but the plant readily seeds itself. For divisions, divide the plant during the early spring or fall when it is dormant. Plant the rhizomes 0.4 inch (10 millimeters) deep with the tip reaching the soil level. Keep the soil moist by mulching. Take cuttings during the summer; start them in sand for planting during the fall.
Asarum hartwegii Marble-leaf ginger	1, 5, 8	Schmidt 1980	Same as *Asarum caudatum*.
Asclepias cordifolia Purple milkweed	1	Schmidt 1980	Requires sun and porous soil.
Asclepias speciosa Butterfly weed	1, 5	Schmidt 1980	Spreads rapidly underground. Butterfly weed is a host plant for the monarch butterfly.
Aster alpigenus Alpine aster	1	Weisberg 1993 Young and Young 1986	
Aster foliaceus Leafybract aster	1e	**Link 1993** Weisberg 1993	The seed ripens between June 1 and September 15. Rub the seed to remove fuzz. Dry the seed quickly. Use mothballs to control insects.
Aster glaudoces Blueleaf aster	1e	**Link 1993**	Seed ripens between August 1 and September 30. Rub the seed to remove fuzz.
Aster integrifolius Thickstem aster	1a: 7	**Link 1993**	Seed ripens between August 15 and September 15. Rub the seed to remove fuzz. Dry the seed quickly. Use mothballs to control insects. Grow in cone-tainers. Direct seed by broadcast seeding and raking.
Aster ledophyllus Cascade aster	1	Weisberg 1993	

Scientific name Common name	Propagation method	References	Remarks
Aster leevis Smooth aster	1e	**Link 1993**	Seed ripens between August 15 and September 30. Direct seed by broadcast seeding and raking.
Aster modestus Modest aster	1e	**Link 1993**	Dry the seed quickly. Use mothballs to control insects. Grow in cone-tainers.
Aster sibericus	1	Densmore and others 1990	
Astragalus spp.	1b	Young and Young 1986	
Astragalus antiselli	1e	Young and Young 1986	
Astragalus eucosmus	1b or 1d	Densmore and others 1990	Inoculate seedlings with a solution of root nodules.
Atriplex spp. Saltbush	1a	Young and Young 1992	Direct seed.
Atriplex canescens Fourwing saltbush	1a: 30–50	Landis and Simonich 1983	Seed ripens between October 20 and March 1. Store seed in the open. Start plants during the spring, summer, or fall. Seeds take 3 to 4 months to grow.
Atriplex confertifolia	2	Landis and Simonich 1983	
Atriplex cuneata	2	Landis and Simonich 1983	
Atriplex lentiformis Quail bush	1e	Harris and Leiser 1979	Direct seed during the late winter or spring.
Baccharis pilularis Coyote bush	1e	Harris and Leiser 1979 Young and Young 1992	Direct seed during the fall.
Baileya spp. Desert marigold	1	Young and Young 1986	Seed requires light for germination.

Scientific name Common name	Propagation method	References	Remarks
Balsamorhiza sagittata Arrowleaf balsamroot	**1a: 56–84**, 8	**Rose and others 1998**	Seed ripens by mid-June. Harvest seed by hand. Clean seed by drying, fanning, and macerating. Stratify seed at 25 degrees Fahrenheit (–4 degrees Celsius). Broadcast seed when sowing and cover the seeds. Fall or winter sowing is recommended. Plants can be salvaged by transplanting root crowns.
Beloperone californica Chaparosa	1e	Young and Young 1992	
Berberis spp. (See also *Mahonia* spp.)	1a: 14–48, 1e, 2, 8, 9, 10 (summer)	Hartmann and others 1990 Young and Young 1992	Separate the seed from the fruit by flotation. Remove all pulp from the seed. Stratify seed at 40 degrees Fahrenheit (4 degrees Celsius) or direct sow the seed during the fall. Root cuttings under mist. Application of 2,000 to 8,000 parts per million IBA (indole-3-butyric acid) aids rooting for some species.
Berberis fremontii (See *Mahonia fremontii*)			
Berberis nervosa Oregon grape (See also *Mahonia nervosa*)	1a: 45–150 3, 4, 5, 7 (summer or fall)	Browse 1979 Potash and Aubry 1997	Seed ripens between August 1 and September 30. Process the seed immediately by flotation or by rubbing the fruit on a screen. Store the seed above freezing without drying. Start seed during the spring. With cuttings, take no more than 5 percent of the donor plant.
Betula glandulosa	1e	Young and Young 1992	Needs light to germinate best.
Betula occidentalis Water birch	1e	Rose and others 1998	Collect strobiles (a fruiting structure characterized by rows of overlapping scales) while they are still green and spreading and dry them during the late summer. Sow the seed during the fall. Seedlings require shade for 2 to 3 months during their first summer.
Betula papyrifera Paper birch	1e, 4	Rose and others 1998	Collect seed from September to November. Pick strobiles while they are still green. Unstratified seed germinates better than stratified seed. Sow seed during the late summer and fall. For cuttings, the timing is critical—

Scientific name Common name	Propagation method	References	Remarks
			shoots should be active with the base of the cutting just becoming firm. Nodal cuttings from 6 to 8 inches (150 to 200 millimeters) long are best. Plant cuttings during warm, dry conditions with good air and moisture.
Bouteloua breviseta Chino grama	1e	**Link 1993**	Seed ripens during November. Seed is difficult to collect because of the short period that it is available, its tendency to shatter, and its low viability.
Bouteloua curtipendula	1e	Young and Young 1986	
Bouteloua hirsuta Hairy grama	1e	**Link 1993**	Seed ripens during November. Seed is easy to collect, but has low viability.
Brickellia californica Brickle brush	1e	Young and Young 1992	
Bromus carinatus Mountain brome	1e	**Link 1993** Young and Young 1986	Seed ripens between June 1 and August 31. Avoid plants with smut. Direct seed. Can be used in a seed-increase program.
Bromus vulgaris Columbia brome	1e	**Link 1993**	Seed ripens between July 1 and August 31. Avoid plants with smut. Direct seed. Can be used in a seed-increase program
Buchloe dactyloides Buffalo grass	1a: 42	Young and Young 1986	Seed requires light and potassium nitrate (KNO_3) during germination.
Calamagrostis breweri Shorthair reedgrass	1, 8	**Link 1993**	Start divisions in January. Use vitamin B1. Don't cover the root crown with soil.
Calamagrostis canadensis Bluejoint reedgrass	1e	**Link 1993** Young and Young 1986	Seed ripens during the spring. Plant seed ¾ to 1 inch (20 to 25 millimeters) deep. Plant in moist to saturated soil with no standing water.
Calamagrostis rubescens Pinegrass	1e	Rose and others 1998	Diurnal fluctuating temperatures are needed: 16 hours at 68 degrees Fahrenheit (20 degrees Celsius) and 8 hours at 86 degrees Fahrenheit

Scientific name Common name	Propagation method	References	Remarks
			(30 degrees Celsius). Needs adequate moisture and light.
Callicarpa spp. Beauty bush	1e, 4	Young and Young 1992 **Link 1993**	Take cuttings from June to September. Treat with 1,000 parts per million IBA (indole-3-butyric acid) talc. Expect 50-percent germination when planting seed in trays. Seedlings should be transplanted to containers.
Callicarpa americana American beautyberry	1e	Young and Young 1992 **Link 1993**	Same as *Callicarpa* spp.
Caltha asarifolia Marshmarigold	8	Weisberg 1993	
Caltha biflora White marshmarigold	1	Weisberg 1993	
Calycanthus occidentalis Western spice bush	1e	Harris and Leiser 1979	Direct seed during the fall.
Carex exserta Shorthair sedge	1e, 8	**Link 1993**	Start divisions during January. Use vitamin B1. Don't cover the root crown with soil.
Carex illota Small-headed sedge	1	Weisberg 1993	
Carex mertensii Mertens sedge	1e	**Link 1993**	Seed ripens between August 1 and September 1.
Carex microptera Smallwing sedge	1a: 60	**Link 1993**	Soak seed for 60 days in water at 33 to 45 degrees Fahrenheit (0.5 to 7 degrees Celsius) in the dark. Plant seed in moist soil that is not submerged in water.
Carex nigricans Black alpine sedge	1, 8	Potash and Aubry 1997	Seed ripens between August 15 and September 30. Ripe seed comes off easily in the fingers. Store seed in the cold for several months to

Scientific name Common name	Propagation method	References	Remarks
			stratify. After direct seeding during early summer, use plastic sheeting on the soil to force germination.
Carex obnupta Slough sedge	1e	**Link 1993**	Sow seed during the fall. Slough sedge needs very wet soil.
Carex paschystachya Thick-headed sedge	1	**Link 1993**	Seed ripens between July 30 and August 30. Seed can be planted during the fall without removing the hull.
Carex phaecephala Dunhead sedge	1	Weisberg 1993	
Carex rossii Ross sedge	1, 8	**Link 1993**	Start divisions during January. Use vitamin B1.
Carex rostrata Beaked sedge	1	Rose and others 1998	Harvest achenes during August or September. Sow seed into moist soil during the fall.
Carex spectabilis Showy sedge	1	Weisberg 1993	
Carex utriculata Sedge	1a: 60	**Link 1993**	Same as *Carex microptera*.
Carpenteria californica Bush anenome	1e, 4	Young and Young 1992	Collect seed between July and October. Bush anemone suckers freely and can be propagated easily by cuttings.
Carya aquatica Water hickory	1a: 30–150	**Link 1993**	Direct seed during the fall. Soak seeds before planting in the spring.
Cassia armata Armed senna	1d	Young and Young 1986	

Scientific name Common name	Propagation method	References	Remarks
Cassiope mertensiana White mountain heather	1, 2, 9, 10	Potash and Aubry 1997	Seed ripens between September 1 and the first snowfall. See appendix C for more detailed information.
Castanopsis chrysophylla Golden chinkapin	1e	Young and Young 1992 **Link 1993**	Seed has 53-percent germination. Expect problems with seedling survival. Poor results with cuttings.
Castilleja spp. Indian paintbrush	1	Link 1993 Young and Young 1986	
Castilleja miniata Common red paintbrush	1a: 28–84	**Rose and others 1998**	Stratify the seed at temperatures between 34 and 41 degrees Fahrenheit (1 and 5 degrees Celsius). Seed germinates at 70 degrees Fahrenheit (21 degrees Celsius), but grows slowly. Seedlings need a constant supply of nitrogen. Seeds germinate best near the roots of other plants they can parasitize.
Cathestecum erectum False grama	1, 8	**Link 1993**	Irrigate, fertilize, and cultivate seedlings. Good stands of false grama are difficult to establish.
Ceanothus arboreus Feltleaf ceanothus	1c	Harris and Leiser 1979	Direct seed during the fall. Soak seed in hot water. Ceanothus can fix nitrogen.
Ceanothus cordulatus	1e	Young and Young 1992	
Ceanothus crassifolius	1a: 90, 1e	Young and Young 1992	
Ceanothus cuneatus Buck brush	1c	Harris and Leiser 1979 Rose and others 1998	Same as *Ceanothus arboreus.*
Ceanothus diversifolius	1: 90, 1e	Young and Young 1992	
Ceanothus fendleri	1e	Young and Young 1992	

Scientific name Common name	Propagation method	References	Remarks
Ceanothus foliosus Wavyleaf ceanothus	1c	Harris and Leiser 1979	Same as *Ceanothus arboreus*.
Ceanothus fresnensis Fresno mat	1a: 90, cuttings	**Link 1993**	Cuttings should be at least 6 inches (150 millimeters) long.
Ceanothus greggii	1a: 60	Young and Young 1992	
Ceanothus impressus Santa Barbara ceanothus	1c	Harris and Leiser 1979	Same as *Ceanothus arboreus*.
Ceanothus integerrimus Deerbush ceanothus	1a: 90, 1e	Young and Young 1992	Plant seed directly during the fall or stratify the seed before planting. Deerbush ceanothus germinates rapidly after wildfires. This plant can fix nitrogen.
Ceanothus leucodermis Whitethorn	1c	Harris and Leiser 1979	Same as *Ceanothus arboreus*.
Ceanothus megacarpus Bigpod ceanothus	1c	Harris and Leiser 1979	Same as *Ceanothus arboreus*.
Ceanothus oliganthus	1a: 90, 1e	Young and Young 1992	
Ceanothus prostratus Squaw carpet		Rose and others 1998 Young and Young 1992	Soak seed in water at 180 degrees Fahrenheit (82 degrees Celsius). Cool the seed, mix it with sand, and place the mixture in a refrigerator. Once the seed swells, sow it in containers. Plants will be ready for outplanting in 2 years.
Ceanothus rigidus	1a: 90, 1e	Young and Young 1992	
Ceanothus sanguineus Redstem ceanothus	1a: 90, 1d	Rose and others 1998 Young and Young 1992	Viable seed will turn dark as it matures. Soak the seed in hot water and stratify it or soak the seed in acid or gibberellin for 30 minutes. Sow seed directly during the fall after heat treatment or pretreat the seed and sow it in spring.

Scientific name Common name	Propagation method	References	Remarks
Ceanothus sorediatus Jim brush	1c	Harris and Leiser 1979 Young and Young 1992	
Ceanothus thyrsiflorus Blueblossom	1c	Harris and Leiser 1979 Young and Young 1992	
Ceanothus velutinus Snowbrush ceanothus	1a: 60–85, 4	Hingston 1982 **Rose and others 1998** Young and Young 1992	Nitrogen fixer. Seed ripens from July to September. Soak seed in hot water and stratify seed before sowing it in flats during December or January. Seedlings are susceptible to damping off (dying suddenly because of fungal attacks). Take cuttings during the summer. Treat them with 0.8-percent IBA (indole-3-butyric acid) and plant them in a damp, sandy mixture of medium- to coarse-textured soils with low nutrient content. Apply bottom heat. Pot seedlings after they have rooted.
Celtis occidentalis	1a: 56–84, 1e, 4, 5	Young and Young 1992	
Celtis reticulata	1a: 84, 1e, 4	Young and Young 1992	
Cephalanthus occidentalis Common buttonbrush	1e, 4	Young and Young 1992	
Ceratoides lanata Winterfat	1e	Young and Young 1992	Seed requires 2 to 3 months afterripening. Plant during cool weather.
Cercidium floridum Palo Verde	1e	Young and Young 1986	
Cercis occidentalis Western redbud	1a: 84, 1c, 1d, 1g	Young and Young 1992 Harris and Leiser 1979	Scarify the seed with acid or soak the seed in boiling water for 1 minute or expose the seed to dry heat, 230 degrees Fahrenheit (110 degrees Celsius), for 9 minutes. Stratify the seed. Direct seed during the fall. Western redbud can fix nitrogen.

Scientific name Common name	Propagation method	References	Remarks
Cercocarpus betuloides Mountain mahogany	1e	Harris and Leiser 1979	Direct seed during the fall.
Cercocarpus ledifolius Curlleaf mountain mahogany	1a	Rose and others 1998 Young and Young 1992 **Link 1993**	Seed ripens during August and September. Stratify seed before sowing or sow the seed into flats and stratify the flats. Provide drainage to prevent root rot.
Cercocarpus montanus Mountain mahogany	1a: 30–90	Rose and others 1998 Young and Young 1992 Landis and Simonich 1983	Fruit ripens during late summer to early fall. Stratify the seed. Sow stratified seed during the spring or sow unstratified seed during the fall. Outplant seedlings after 1 to 2 years. Mountain mahogany can fix nitrogen.
Chaenactis douglasii Douglas dustymaiden	1	**Link 1993** Young and Young 1986	Seed ripens during August.
Chamaebatia foliolosa Bearmat	1a: 28–84	Young and Young 1992	
Chamaebatiaria millefolium Fernbrush	1a: 90, 8	**Link 1993**	Seed should be sown directly into growing containers and thinned to one plant per cell to increase survival.
Chamaecyparis Port Orford cedar	1f: 30/30	Young and Young 1986	
Chamaecyparis nootkatensis Alaska cedar	1a: 21	Young and Young 1992	
Chilopsis linearis Desert willow	1a: 3	Young and Young 1992	Sow seed ½ inch (13 millimeters) deep during the spring. Desert willow can be propagated by cuttings.
Chimaphila umbellata Prince's pine	**2**, 8	**Rose and others 1998**	Prince's pine flowers from June to August. Take summer stem cuttings and root them in a mixture of sand and peat. Plant them in late spring about 6 to 8 inches (150 to 200

Scientific name Common name	Propagation method	References	Remarks
			millimeters) apart. Prince's pine produces long, fast-growing rhizomes. Underground stems can be divided.
Chrysolepsis chrysophylla Golden chinkapin	1e, 9, grafting, budding	Rose and others 1998	Pick burs after they are ripe in late summer, but before they open. Plant the seed directly.
Chrysolepsis sempevirens Sierra chinkapin	1e	Link 1993 Young and Young 1992	Sierra chinkapin has 53-percent germination. Expect problems with seedling survival.
Chrysopsis villosa Golden aster	1e	Young and Young 1986	Golden aster has 30-percent germination. Expect problems with seedling survival and poor results with cuttings.
Chrysothamnus nauseosus Rubber rabbitbrush	1a: 0–120	Landis and Simonich 1983	Start seed during the spring or summer. Seedlings take 3 to 4 months to grow.
Chrysothamnus viscidiflorus Green rabbitbrush	1a: 0–28	Young and Young 1992	
Circium edule Edible thistle	1	Weisberg 1993	
Clarkia spp.	1	Schmidt 1980	Direct sow the seed or propagate *Clarkia* in flats. *Clarkia* is an annual.
Clarkia unguiculata	1e	Young and Young 1986	
Clematis spp.	1a: 56–168	Young and Young 1992	Propagation requirements vary by species.
Cleome spp. Rocky Mountain bee plant	1	Young and Young 1986	Rocky Mountain bee plant is difficult to germinate. It needs light, potassium nitrate (KNO_3) enrichment, and warm temperatures.
Coleogyne ramosissima Blackbrush	1a	Young and Young 1992	

Scientific name Common name	Propagation method	References	Remarks
Collinsia grandiflora Blue lips	1	Schmidt 1980	Direct sow the seed during the fall or spring or propagate in flats. *Collinsia* is an annual.
Collinsia heterophylla Purple Chinese houses	1	Schmidt 1980	Direct sow the seed during the fall or spring or propagate in flats. *Collinsia* is an annual.
Colubrina californica Colubrina	1e	Young and Young 1986	
Coreopsis spp.	1	Young and Young 1986	*Coreopsis* requires light and potassium nitrate (KNO_3) enrichment.
Coreopsis calliopsidea Leafystem coreopsis	1	Schmidt 1980	Direct sow the seed during November or December. *Coreopsis* prefers sunny areas and sandy loam. *Coreopsis* is an annual.
Coreopsis douglasii Douglas's coreopsis	1	Schmidt 1980	Direct sow the seed. Coreopsis is an annual.
Coreopsis stillmanii Stillman's coreopsis	1	Schmidt 1980	Direct sow the seed. Coreopsis is an annual.
Coreopsis tinctoria Plains coreopsis	1	**Link 1993**	Seed ripens around July 1.
Cornus spp. Dogwood	1, 9 (spring and summer)	Hartmann and others 1990 Weisberg 1993 **Young and Young 1986**	Separate the seed from the fruit by flotation. Dogwood stones can be sown without extracting the seed from the fruit. Sow seed immediately after collecting it. Some species can be started from cuttings.
Cornus canadensis Bunchberry dogwood	1b, 1f: 45/140, 9	**Link 1993**	Collect soil and duff from a native stand to provide mycorrhizal inoculum. Seed germinates best if it is sown during the fall right after it has been cleaned.
Cornus nuttallii Pacific dogwood	1a: 90–120, 1b, 1e, 4	Rose and others 1998	Sow fresh seed in fruit directly during the fall or macerate the fruit and separate the seed using floatation. Scarify stored seed for 4 hours, stratify seed at 37 degrees Fahrenheit (3 degrees

Scientific name Common name	Propagation method	References	Remarks
			Celsius), and sow during the fall. Take cuttings during June or July. When transplanting, place transplants in a ring of native shrubs to protect them from the sun.
Cornus stolonifera Redosier dogwood	1a: 60–90, 2, 3, 9	Shaw 1983 Potash and Aubry 1997 Rose and others 1998	Seed ripens between July 1 and October 31. Sow fresh seed or fruit during the fall. Branch tips 2 to 3 inches (50 to 76 millimeters) long can be collected during the late summer and planted during late spring. Collect 2- to 4-foot- (0.6- to 1.2-meter-) long whips of 1-year-old wood during midwinter. Outplant the whips during late winter or early spring. Whips can be planted directly in moist soil.
Corylus cornuta California hazelnut	1a: 56–168	Young and Young 1992	Plant during the fall or chill the seed before planting.
Cowania mexicana Cliffrose	1e, 1f: 28/30	Landis and Simonich 1983 **Young and Young 1992**	Seeds are not likely to germinate without treatment. Chilling seed for 2 weeks at 5 degrees Celsius produced mean optimal germination of 55 percent.
Crataegus columbiana Columbia hawthorn	1a: 120–180	Young and Young 1986	The seed must be treated in moist medium at low temperature before it will germinate.
Crataegus douglasii Douglas hawthorn	1a: 84–112, 1b, 9	Rose and others 1998	Seed ripens from late July through August. Use flotation to separate the seed and stratify the seed at 41 degrees Fahrenheit (5 degrees Celsius). Scarify the seed in acid for up to 3 hours. Sow the seed during early fall.
Crepis acuminata Hawk's beard	1e	Young and Young 1986	
Crossosoma californicum	1e	Young and Young 1992	
Cupressus spp. Cypress	1a: 21	Young and Young 1992	Many species. The seed of most species needs to be prechilled.
Dalea spp. Indigo bush	1b, 1e	Young and Young 1992	The seed needs to be scarified.

Scientific name Common name	Propagation method	References	Remarks
Danthonia californica California oat grass	1a: 84, 8	Link 1993 **Rose and others 1998**	Pretreat divisions with vitamin B1. Collect plants when they are dormant. Bring them into the greenhouse. In January, divide the plants, making sure each division has a single root system. Keep the plants moist at 64 to 70 degrees Fahrenheit (18 to 21 degrees Celsius). After 2 weeks, move the plants to a lathhouse. If you are propagating from seed, soak the seed for 1 to 3 days. Stratify the seed at 34 to 41 degrees Fahrenheit (1 to 5 degrees Celsius).
Danthonia compressa Mountain grass	1	**Link 1993**	*Danthonia* does not grow well in direct sunlight.
Danthonia intermedia Timber oatgrass	1a: 30–60	Weisberg 1993 **Link 1993**	Plant the seed directly during the fall.
Dasiphora fruticosa Shrubby cinquefoil	1a: 60, 4, 9	Densmore and others 1990 Landis and Simonich 1983 **Rose and others 1998** Link 1993	Direct sow the seed or stratify it at 34 degrees Fahrenheit (1 degree Celsius). Take softwood cuttings in July. Dip cuttings in 1,000 parts per million indole-3-butyric acid (IBA) and root them in a mixture of peat, perlite, and sand.
Delphinium spp. Larkspur	1a: 112	Young and Young 1986	
Dendromecon rigida Stiff bushpoppy	1	Young and Young 1992	Sow the seed in moist medium at temperatures alternating diurnally from 41 to 72 degrees Fahrenheit (5 to 22 degrees Celsius).
Deschampsia atropurpurea Mountain hairgrass	1, 1a: 112	Potash and Aubry 1997 Rose and others 1998	Seed ripens from August 1 to October 31. Start plants during late May or early June. The seed takes 30 days to germinate.
Deschampsia caespitosa Tufted hairgrass	1	**Rose and others 1998**	Keep seed for 6 weeks at 68 degrees Fahrenheit (20 degrees Celsius) for 16 hours and 50 degrees Fahrenheit (10 degrees Celsius) for 8 hours, then reduce the temperatures to 59 degrees

Scientific name Common name	Propagation method	References	Remarks
			Fahrenheit (15 degrees Celsius) for 16 hours and 41 degrees Fahrenheit (5 degrees Celsius) for 8 hours. Sow seed during the fall or spring.
Dicentra formosa Bleeding heart	1a: 48, **8**	Link 1993 **Rose and others 1998** Young and Young 1986	Seed ripens from August through early September. Sow seed fresh during late summer or fall. Divide rhizomes after the plant has flowered.
Distichlis spicata Desert saltgrass	1	Young and Young 1986	Desert saltgrass has low seed production. The seed germinates best with temperatures of 50 degrees Fahrenheit (10 degrees Celsius) at night and temperatures of 105 degrees Fahrenheit (41 degrees Celsius) during the day.
Dodecatheon clevelandii Shootingstar	1e	Young and Young 1986	
Downingia concolor Fringed downingia	1	Schmidt 1980	Sow seed thickly directly into the soil. Provide ample water. Fringed downingia is an annual.
Downingia cuspidata Toothed downingia	1	Schmidt 1980	Same as *Downingia concolor.*
Draba aureola Alpine draba	1	Weisberg 1993	
Dryas drummondii Yellow dryad	1	**Link 1993**	Seed ripens from August 1 to 15.
Dyssodia cooperi	1	Young and Young 1992	Seed has about 20-percent germination.
Eastwoodia elegans	1	Young and Young 1992	Seed has about 35-percent germination.
Eleocharis coloradoensis Spikerush	1a	Young and Young 1986	Seed should be stored in cold water.

Scientific name Common name	Propagation method	References	Remarks
Elymus canadensis Wild rye	1a: 14	Young and Young 1986	
Elymus cinereus	1e	Young and Young 1986	
Elymus elymoides Bottlebrush squirrel tail	1e	**Link 1993**	Seed directly during the spring or fall. Expect 40- to 60-percent germination.
Elymus glaucus Blue wild rye	1e, 13	Potash and Aubry 1997 Young and Young 1986	Seed ripens from August 1 through October 31. Heads shatter, so collect seed during the soft- to hard-dough phase or as the heads turn gold. A nursery can produce 10 to 50 pounds of seed per acre (11 to 56 kilograms per hectare) during the first year and 250 to 600 pounds of seed per acre (280 to 673 kilograms per hectare) during the second year. Plant seed at 10 to 50 pure live seeds per foot (30 to 150 pure live seeds per meter) or 10 pounds of seeds per acre (11 kilograms per hectare) if the seeds are drilled. Plant 20 pounds of seeds per acre (22 kilograms per hectare) if they are broadcast. Sow the seed during the fall and cover it lightly with soil and mulch.
Elymus innovatus	1	Densmore and others 1990	
Elymus salinus Saline wild rye	1a: 30	**Link 1993**	Seed ripens from July 15 through July 30. Expect 30- to 70-percent germination.
Elymus triticoides	1e	Young and Young 1986	
Encelia spp.	1e	Young and Young 1992	
Ephedra californica	1e	Young and Young 1992	
Ephedra nevadensis Gray ephedra	1e	Young and Young 1992	

Scientific name Common name	Propagation method	References	Remarks
Ephedra viridis Mormon tea	1e	Landis and Simonich 1983 Shaw 1983 Young and Young 1992	Seed ripens from July 15 to September 1. Store seed in the open. Start seed during the spring, summer, or fall. Plants take 4 to 6 months to grow.
Epilobium spp. Willowherb	1	Weisberg 1993	
Epilobium angustifolium Fireweed	1, 5	Potash and Aubry 1997	Seed ripens from July 15 to September 30 when 50 percent or more of the flowering surface has fluffed out. Collect the seed during dry weather. Cut the entire flower head and store it upside down in paper bags to mature. Seed may not need to be cleaned. Sow the seed during the fall or spring with a seed spreader. Mix the seed with three parts medium vermiculite and one part fine peat. Root cuttings should be 12 to 24 inches (31 to 610 millimeters) long. Plant root cuttings directly, about 2 inches (50 millimeters) deep and 4 inches (100 millimeters) apart.
Eremocarpus setigerus Doveweed	1e	Young and Young 1986	
Ericameria bloomeri Bloomer rabbitbrush	1	**Link 1993**	Expect germination to be 20 percent or less.
Erigeron peregrinus Subalpine daisy	1	Weisberg 1993 Young and Young 1986	
Eriogonum fasciculatum California buckwheat	1	Young and Young 1992	Seed ripens during August. Germination is epigeal (the cotyledons are photosynthetic above the ground). Considerable dormancy. Low viability.
Eriogonum heermannii Zigzag bush	1	Young and Young 1992	

Scientific name Common name	Propagation method	References	Remarks
Eriogonum inflatum Desert trumpet	1	Young and Young 1992	
Eriogonum marifolium Wild buckwheat	1a: 48–56	**Link 1993**	Establish plants from seed in a greenhouse. Expect 14- to 19-percent germination.
Eriogonum nudum Bare stem buckwheat	1e	**Rose and others 1998**	Seed ripens during July and August. Plant during the fall in coarse soil. Cover the seed with sphagnum moss. Transplant seedlings into 3-inch (76-millimeter) pots during the spring.
Eriogonum umbellatum Sulfur buckwheat	1e	Rose and others 1998	Same as *Eriogonum nudum*.
Eriophyllum confertiflorum Golden yarrow	1e	Young and Young 1986	
Eriophyllum nevinii Catalina silver lace	1e	Young and Young 1986	
Erythronium montanum Avalanche lily	1	Weisberg 1993	
Eschscholzia spp. California poppy	1e	Schmidt 1980 Young and Young 1986	*Eschscholzia* will self-seed abundantly.
Euonymus occidentalis Western burning bush	1a: 84	Young and Young 1986	
Euphorbia spp.	1a: 56	Young and Young 1986	
Fallugia paradoxa Apache plume	1e	Young and Young 1992	Sow seed during the spring or during summer rains.

Scientific name Common name	Propagation method	References	Remarks
Festuca spp.	1a: 5	Young and Young 1986	*Festuca* requires light and potassium nitrate (KNO_3) enrichment.
Festuca altaica	1	Densmore and others 1990	
Festuca idahoensis Idaho fescue	1	Weisberg 1993	
Festuca rubra Red fescue	1	Densmore and others 1990	
Festuca viridula Green fescue	1a: 112	Weisberg 1993 **Link 1993**	Seed ripens from June to September. Cold stratify the seed before planting it in a greenhouse. Transplant the seedlings.
Fouquieria splendens Ocotillo	1	Young and Young 1986	
Fragaria spp. Strawberry	1, 4, 8	Potash and Aubry 1997	Separate the seed from the fruit by flotation. Germination increases after exposure to light and a 2- to 3-month period of cold. Cuttings can be taken from runners.
Fragaria vesca Woodland strawberry	1, 4, 8	Rose and others 1998	Same as *Fragaria* spp.
Fragaria virginiana Broadpetal strawberry	1, 4, 8	Rose and others 1998	Same as *Fragaria* spp.
Fraxinus spp. Ash	1f: 30–90/60–90	Young and Young 1986	
Fraxinus velutina Arizona ash	1a: 90, 1e	Harris and Leiser 1979 **Young and Young 1992**	Direct seed during the fall or prechill the seed.
Fremontodendron californicum Flannel bush	1c	Harris and Leiser 1979 Young and Young 1992	Direct seed during the fall. Soak seed in hot water.

Scientific name Common name	Propagation method	References	Remarks
Fumariaceae	1	Young and Young 1986	
Gaillardia aristate Blanketflower	1e	Link 1993	
Galvezia speciosa Bush snapdragon	1e	Young and Young 1986	
Garrya flavescens Silk tassel	1a: 30–120, 4	Young and Young 1992	Seed ripens from June through December. Macerate the fruit and use flotation to separate the seed. Prechill the seed before soaking it in 100 parts per million of gibberellin.
Garrya fremontii	1a: 90	Young and Young 1992	Seed ripens from June through December.
Garrya ovatifolia Slender wintergreen	1, **2**	**Potash and Aubry 1997**	Berries are ripe during the early fall when they are dark blue. Seed is difficult to germinate. Take cuttings between August 1 and October 31. Cuttings take 10 to 12 weeks to grow.
Garrya shallon Salal	1e, 2, 5, 8, 9	Potash and Aubry 1997 Rose and others 1998 Young and Young 1992	Collect seed as recommended for *Garrya ovatifolia*. The seed has a low germination rate. Cuttings take 10 to 14 months to grow. Take stem cuttings that are 6 inches (150 millimeters) long, cutting just into the cambium. Start cuttings in perlite.
Garrya wrightii	1a: 90	Young and Young 1992	
Gaultheria hispidula Creeping snowberry	1a: 30–120	Young and Young 1992	Seed requires light to germinate. Sow seed during the fall.
Geranium viscosissimum Sticky geranium	1e	Link 1993 Young and Young 1986	Direct plant the seed into containers with a mixture of peat and perlite.
Geum triflorum Prairie smoke	1e	Link 1993	Direct plant the seed with a mixture of grass and forb seed. Plant the seed in flats for transplanting.

Scientific name Common name	Propagation method	References	Remarks
Gilia spp.	1	Schmidt 1980	Direct sow the seed during the fall (best) or during the early spring.
Grayia brandegei Spineless hopsage	1g	Young and Young 1992	Stratify the seed at 41 degrees Fahrenheit (5 degrees Celsius) for 16 hours and at 50 to 86 degrees Fahrenheit (10 to 30 degrees Celsius) for 8 hours.
Grayia spinosa Spiny hopsage	1g	Young and Young 1992	Same as *Grayia brandegei*.
Haplopappus parishii Parish goldenweed	1e, 4	Young and Young 1992	
Hedysarum alpinum	1a: 60	Densmore and others 1990	Inoculate the seedlings with a solution of root nodules.
Hedysarum boreale Northern sweetvetch	1	Link 1993	Prechill seed for 7 to 10 days. Inoculate the media with native soil.
Hedysarum sulfurescens Yellow sweetvetch	1	Link 1993	Same as *Hedysarum boreale*.
Helianthella uniflora Coneflower helianthella	1e	Link 1993	Direct seed.
Helianthus spp. Sunflower	1a	Young and Young 1986	
Hemizonia spp. Tarweed	1e	Young and Young 1986	
Heracleum lanatum Cow-parsnip	1e	Rose and others 1998	Seed ripens during August. Collect seed by hand during the late summer after dark stripes become evident. No stratification is needed, but leach the seed in water for 4 hours before planting. Broadcast the seed during the fall.

Scientific name Common name	Propagation method	References	Remarks
Heteromeles arbutifolia Christmas berry	1e	Harris and Leiser 1979 Young and Young 1992	Direct seed during the fall.
Heterotheca villosa Hairy golden aster	1e, 13	Link 1993	Direct seed or grow in containers. The timing of seed collection is critical. Seed shatters only a few days after it is ready.
Heuchera cylindrica Roundleaf alumroot	1e	Link 1993	
Hibiscus spp. Rose mallow	1e, 4	Young and Young 1992	Some introduced species are invasive.
Hieraceum albiflorum White hawkweed	1a: 90	**Potash and Aubry 1997**	Collect the seed when half of the flowers are still in bloom to avoid confusing this species with noxious hawkweeds. Shake the seed into a paper sack or collect the entire flower heads. Sow the seed during the fall, or stratify the seed and sow it during the spring.
Hieraceum gracile Slender hawkweed	1	Weisberg 1993	
Hilaria jamesii (See *Pleuraphis jamesii*)			
Hofmeisteria pluriseta Arrowleaf	1e	Young and Young 1992	
Holodiscus discolor Oceanspray	**1a**: **126**, 2, 3	**Potash and Aubry 1997** Rose and others 1998 Young and Young 1992	Seed ripens from September 1 to November 30 when it is no longer green. It drops soon afterward. Look for dark brown flower heads. If the flower heads are grey-brown, the seed probably has dropped already. Shake the seed into a bucket. Seed viability and germination are low. Sow the seed during the fall.
Holodiscus dumosus var. *glabrescens* Bush oceanspray	1a: 54–140	Link 1993	Dry the seed well before rubbing it by hand and sieving it.

Scientific name Common name	Propagation method	References	Remarks
Hordeum brachyantherum Meadow barley	1e	Rose and others 1998	Seed ripens during the late summer. Sow fresh seed during the fall at a depth of two times the seed height in a mixture of sand, pumice, and peat (1:1:1). Place the containers in a cold frame.
Hymenoclea salsola White burrowbush	1e	Young and Young 1986	
Ipomopsis aggregata Scarlet gilia	**1e**	Link 1993 **Rose and others 1998**	Fruit ripens during the summer. Plant the seed into flats. Keep the flats moist. Few plants were produced by direct seeding. Stratifying the seed did not improve germination.
Iris spp.	8	Weisberg 1993	
Isomeris arborea Bladder-pod	1e	Harris and Leiser 1979	Direct seed during the fall.
Juglans californica hindsii California black walnut	1a: 156, 1e	Harris and Leiser 1979 **Young and Young 1992**	Direct seed during the fall or prechill the seed and sow it during the spring.
Juncus mertensianus Merten's rush	1	Weisberg 1993	
Juncus parryi Parry's rush	1, **8**	Link 1993	Take divisions in January. Use Vitamin B1. Keep divisions in a cold frame for 7 days before moving them to a lathhouse. Plant divisions no deeper than the crown. Divisions will die if they are planted too deep.
Juniperus spp. Juniper	1d then a: 120, 1e, **9** (summer), cuttings of prostrate forms	Hartmann and others 1990 Weisberg 1993 Young and Young 1986	Use flotation to separate the seed from the fruit. Direct sow the seed during the fall. Take cuttings during the late fall or winter by stripping growing tips that are 2 to 6 inches (50 to 150 millimeters) long from older branches, leaving the "heel" (a small piece of old wood). Use indole-3-butyric acid (IBA). The rooting medium should be medium-coarse sand or a 10:1 mixture of perlite and peat moss. Apply high humidity and intense light. Apply bottom heat of 65 degrees Fahrenheit (18

Scientific name Common name	Propagation method	References	Remarks
			degrees Celsius) for 6 weeks before raising the temperature to 70 to 75 degrees Fahrenheit (21 to 24 degrees Celsius) to encourage rooting.
Juniperus communis Mountain juniper	1f: 90/90, **2**, 3	**Weisberg 1993** Rose and others 1998 Young and Young 1992	Sow seed during the fall or spring. Cover the seed with a layer of firm soil or sand.
Juniperus occidentalis Western juniper	1a: 30–60	Young and Young 1992	Stratify seed at 34 to 41 degrees Fahrenheit (1 to 5 degrees Celsius).
Juniperus osteosperma Utah juniper	1f: 30/60	Young and Young 1992	
Juniperus scopulorum Rocky Mountain juniper	1f: 60/40	Landis and Simonich 1983 Shaw 1983 Young and Young 1992	Seed ripens between September 1 and December 30. Start during the spring or summer. Plants take 12 to 16 months to grow.
Kalmia latifolia	9 (summer)	Weisberg 1993	
Kochia americana Red molly	1	Young and Young 1992	Direct seeding is not recommended. Transplant seedlings to an extremely arid and saline alkaline environment. Will naturalize.
Koeleria cristata Junegrass	1e	Rose and others 1998	Seed is produced during the second year. Treat the seed with fungicide to protect it from rust. Plant seed during the fall from 0.2 to 0.4 inch (5 to 10 millimeters) deep. Cover the seed with sawdust.
Larix spp.	1a: 20–60, 1e	Young and Young 1986	Most larch species germinate fairly well without pretreating the seed.
Larix laricina Tamarack	1a: 21, 1e	Young and Young 1992	Stratify the seed at 37 to 41 degrees Fahrenheit (3 to 5 degrees Celsius).

Scientific name Common name	Propagation method	References	Remarks
Larix lyalli Subalpine larch	1b	Young and Young 1986	Soak the seed for 24 hours in a 3-percent solution of hydrogen peroxide.
Larix occidentalis Western larch	1a: 18, 1e	Rose and others 1998 Young and Young 1992	Pick cones from trees when they are ripe and dry. Open cones with heat by putting them where they are exposed to the sun or in a kiln or heated room. Sow the seed during the fall or spring about 0.2 inch (5 millimeters) deep. Mulch.
Larrea tridentata Creosote bush	1b	Young and Young 1992	Collect ripe fruit during the spring and early summer. Dehull the seed.
Lathyrus spp. Wild pea	1b	Young and Young 1986	Treat the seed with hot water.
Lavatera assurgentiflora Malva rose	1e	Young and Young 1986	
Layia spp.	1	Young and Young 1986 Schmidt 1980	Requires afterripening and light. Seed germinates in 2 weeks.
Ledum glandulosum Western Labrador tea	1, 3	Link 1993 Young and Young 1992	Cuttings taken in mid-December will root well.
Lepidium fremontii Bush peppergrass	1	Young and Young 1986	Very dormant seed. No germination procedures have been developed.
Lepidospartum squamatum Scalebroom	1e	Young and Young 1986	
Leptarrhena pyrolifolia Leatherleaf saxifrage	1	Weisberg 1993	
Libocedrus decurrens Incense cedar	1a: 30–60	Young and Young 1986	

Scientific name Common name	Propagation method	References	Remarks
Lilium spp. Lily	5, 8	Young and Young 1986	
Linanthus spp.	1	**Schmidt 1980**	Sow seed during the fall. Cover the seed with branches to prevent birds from eating the seed.
Linnaea borealis Twinflower	1a: 60, 2, 4, 8	**Potash and Aubry 1997** Rose and others 1998	Cuttings will grow in 8 to 10 months. Plant the seed during the fall. If seed will be planted during the spring, stratify it at 34 degrees Fahrenheit (1 degree Celsius).
Linum grandiflorum Flowering flax	1b	Young and Young 1986	Germinate the seed without light.
Linum perenne lewisii Wild blue flax	1b	Young and Young 1986	Same as *Linum grandiflorum*.
Lithocarpus densiflorus Tanbark-oak	1e	Harris and Leiser 1979 Young and Young 1992	Direct seed during the fall.
Lonicera spp.	1a: 60–90, 3, 4	Hartmann and others 1990 Young and Young 1992	Use flotation to separate the seed from the fruit. Direct sow the seed during the fall ¼ inch (6 millimeters) deep and apply mulch or incubate the sown seed at 20 to 30 degrees Celsius. About 15 percent of the seed will mature to the seedling stage. Most species can be propagated from hardwood cuttings taken during the spring. Take leafy softwood cuttings during the summer and grow them under mist.
Lonicera involucrata Bush honeysuckle (Bearberry honeysuckle)	1a: 45–60, 2, 3, 4	Link 1993 Rose and others 1998	Cuttings have been very successful. Growth that was 1 year old and older rooted well without hormone treatment. If you are propagating from seed, sow the seed during the fall or stratify the seed for a long time.
Lotus spp.	1b	Young and Young 1986	Hot-water treatment is recommended, but it will reduce the seed's viability.

Scientific name Common name	Propagation method	References	Remarks
Luetkea pectinata Partridgefoot	**1**, 2, 8	**Potash and Aubry 1997**	Seed ripens from August 1 to September 30. Seed drops quickly. Flower heads can be cut when the fruits are red. The heads can be stored in open paper bags until they are ripe. Cuttings should be larger diameter.
Lupinus albifrons White-leaf lupine	1c	Harris and Leiser 1979 Young and Young 1992	Soak seed in hot water. Direct seed during the fall. This plant fixes nitrogen.
Lupinus arboreus	1c	Harris and Leiser 1979	Same as *Lupinus albifrons*.
Lupinus arcticus	1b, 1d	Densmore and others 1990	Inoculate seedlings with a solution of root nodules. Greenhouse pathogens may infect these plants.
Lupinus covillei	1	Link 1993	No treatment needed for fresh seed. Scarify dried seed or treat the seed with hot water.
Lupinus elmeri Dwarf lupine	1	Link 1993	Same as *Lupinus covillei*.
Lupinus latifolius Broadleafed lupine	1b, **3**	**Potash and Aubry 1997** Rose and others 1998	Seed ripens from June 1 to September 31. The pods explode. Cut the entire flower head when the lower pods are grayish tan. Seed takes 2 weeks to ripen. Sow the fresh seeds with no treatment. Stored seed should be abraded or soaked for 1 to 16 hours in boiling water. Inoculate with root nodules. Take cuttings from the side shoots of hardened stems during the spring.
Lupinus lepidus Prairie lupine	1b	Link 1993	Soaking seed in hot water may soften the seed coat.
Lupinus sericeus Silky lupine	1b	Link 1993	Seed should be inoculated with the appropriate *Rhizobium*. Direct seeding is best for silky lupine, which should not be handled any more than necessary.

Scientific name Common name	Propagation method	References	Remarks
Luzula campestris Field woodrush	1	Weisberg 1993	
Luzula parviflora Small-flowered woodrush	1	Weisberg 1993	
Lycium andersonii Anderson's wolfberry	1e	Young and Young 1992	
Lysimachia ciliata Fringed loosestrife	1	Young and Young 1986	Seed requires light for germination.
Machaeranthera Tansyaster	1	Young and Young 1986	Tansyaster seeds germinate better after receiving 2 weeks cool, moist treatment.
Madia spp. Tarweed	1e	Young and Young 1986	
Mahonia spp. Oregon grape	1a, 1e, 8, 9, 10 (summer)	Hartmann and others 1990 Young and Young 1992 Weisberg 1993	Separate the seed from the fruit by flotation.
Mahonia aquifolium Shining Oregon grape	1c then 1a: 90, 2, 4, 9	Rose and others 1998 Hartmann and others 1990	Seeds ripen during July and August. Macerate the fruit and separate the seed using flotation. Sow the seed immediately or stratify the seed and sow it during the spring. Heeled, nodal, and basal cuttings can be taken into the fall. Shining Oregon grape is susceptible to fungus, root rot, and mildew.
Mahonia fremontii Desert barberry	1e or 1a: 45	**Link 1993**	Although it is best to separate the seed from the fruit, entire berries can be planted.
Mahonia nervosa Oregon grape	1a: 42, 2, 4	Rose and others 1998	Macerate the fruit and separate the seed using flotation. Sow seed immediately into a mixture

Scientific name Common name	Propagation method	References	Remarks
			of soil and sand. Stratify the seed at 39 degrees Fahrenheit (4 degrees Celsius) and sow it during the spring. For cuttings, see *Mahonia aquifolium*.
Mahonia repens Creeping Oregon grape	1f: 30 cold/60 warm/196 cold, 4, 9	Rose and others 1998	Stratify seed at 34 degrees Fahrenheit (1 degree Celsius) and 68 degrees Fahrenheit (20 degrees Celsius) or at 36 degrees Fahrenheit (2 degrees Celsius) for 16 weeks in gibberellin. Seed can be sown directly during the fall.
Maiathemum dilatatum False lily-of-the-valley	1, **5**	Potash and Aubry 1997	Berries ripen from July 15 to September 30. Plant whole berries. Seed takes 2 years to germinate.
Malus spp. Apple	1a, 1e	Young and Young 1992	Sow untreated seed in the fall, or prechill the seed for planting during the spring.
Melica harfordii Harford's melic	1e	Rose and others 1998	Plant the seed about 0.25 to 0.4 inch (6 to 10 millimeters) deep during the fall. Cover the seed with sawdust. No fungal problems were reported.
Melica spectabilis Onion grass	1a: 80	Link 1993	Seed needs to be stratified at 32 degrees Fahrenheit (0 degrees Celsius) for 80 days. Direct seed.
Menodora scabra Rough menodora	1e	Young and Young 1992	
Mentzelia laevicaulis Blazing star	1e	Young and Young 1986	
Menyanthes trifoliata Bog buckbean	8	Weisberg 1993	
Mertensia paniculata	1	Densmore and others 1990	

Scientific name Common name	Propagation method	References	Remarks
Mimulus lewisii Pink monkey-flower	1e	Weisberg 1993 Young and Young 1986	
Monardella lanceolata Mustang mint	1e	Young and Young 1986	
Monardella macrantha	1e	Young and Young 1986	
Monardella odoratissima	1a: 84, 1e	Young and Young 1986	No treatment necessary for fresh seed. Dry seed requires stratification.
Myosotis alpestris	1	Densmore and others 1990	
Myrica californica Pacific bayberry	1a: 30–90	Young and Young 1992	Sow seed during the fall or prechill the seed.
Myrica hartwegii Sierra sweet bay	1a: 84	Young and Young 1986	
Nama lobbii Woolly nama	1c, 1g	Young and Young 1992	Leach seeds under mist, then soak them in gibberellin. Remove embryos from seed coat.
Oemleria cerasiformis Indian plum or osoberry	1a: 60–120, 2	Weisberg 1993 **Young and Young 1992**	
Oenothera hookeri Evening primrose	1e	Young and Young 1986	
Olneya tesota Desert ironwood	1e	Young and Young 1992	Stored seed should be scarified mildly and soaked for at least 24 hours before planting.
Oplopanax horridum Devil's club	1, 4, 9	**Potash and Aubry 1997** Rose and others 1998	Seed ripens from July 1 to September 31, about 4 weeks after flowering. The seed is shed quickly once the bright red fruit begins fading to brown. Cuttings should be about 6 inches (150 millimeters) long. Propagation is slow by all methods.

Scientific name Common name	Propagation method	References	Remarks
Opuntia spp. Prickly pear	1d	Young and Young 1986	Soak the seed for 30 to 60 minutes in sulfuric acid.
Oryzopsis hymenoides Indian ricegrass	1d	Young and Young 1986	
Osmaronia cerasiformis (See *Oemleria cerasiformis*)			
Osmorhiza occidentalis Sweet anise	1e	Rose and others 1998	Seed ripens during August and September. Collect the seed by hand. Plant seed directly during the fall about ¼ inch (6 millimeters) deep.
Oxalis oregana Wood sorrel	1e, **8**	Weisberg 1993 **Rose and others 1998**	Plant seeds into flats and keep them moist. Mature rhizomes can be divided during the early spring and replanted about ½ inch (13 millimeters) deep.
Oxytropis campestris	1b, 1d	Densmore and others 1990	Inoculate the seedlings with a solution of root nodules.
Oxytropis deflexa	1b, 1d	Densmore and others 1990	Same as *Oxytropis campestris*.
Oxytropis splendens Showy locoweed	1e	Link 1993	
Pachystima myrsinites Oregon boxwood	2, 9	**Potash and Aubry 1997** Rose and others 1998	Collect cuttings from August 15 to September 15. Rooting hormone is required. Start the cuttings in a mixture of perlite and vermiculite.
Paeonia brownii	1a: 84	Young and Young 1986	
Panicum dichotomiflorum	1b	Young and Young 1986	Scarify seed with acid.
Panicum obtusum	1b	Young and Young 1986	Scarify seed with acid for 90 minutes. Enrich the planting medium with potassium nitrate (KNO_3).

Scientific name Common name	Propagation method	References	Remarks
Penstemon spp. Beardstongue	1a: 28–56, 2	Weisberg 1993 Link 1993 Young and Young 1986	Sow seed during the fall or stratify the seed.
Penstemon albertinus Albert penstemon	1a: 30	Link 1993	Soak the seed in water for 24 hours, then freeze the seed for 30 days.
Penstemon confertus Yellow penstemon	1a: 30	Link 1993	Same as *Penstemon albertinus*.
Penstemon lyallii Lyall penstemon	1a: 30	Link 1993	Same as *Penstemon albertinus*.
Penstemon procerus Small-flowered penstemon	1a, 5	Rose and others 1998	Seed ripens during mid-August. Requires stratification at 68 degrees Fahrenheit (20 degrees Celsius) in the light and 86 degrees Fahrenheit (30 degrees Celsius) in the dark. Sow seed 0.08 inch (2 millimeters) deep during March. Keep the flats at 59 degrees Fahrenheit (15 degrees Celsius) for transplanting outdoors during May. Take cuttings from nodes during August. Place the cuttings in sandy soil in a cold frame.
Pentaphylloides floribunda (See *Dasiphora fruticosa*)			
Peraphyllum ramosissimum Squaw apple	1a: 90	Young and Young 1992	
Petalonyx thurberi	1	Young and Young 1992	Good seed is difficult to collect. Germination increases after seed has been stored.
Petesites frigidus Coltsfoot	1e, 8	Weisberg 1993 Potash and Aubry 1997	Seed ripens from May 15 to June 15 when the flower heads are opening. Shake the seed into a bag or collect the entire flower head. Dry the seed carefully. Sow the seed immediately. It cannot be stored.

Scientific name Common name	Propagation method	References	Remarks
Peucephyllum scottii Pigmy cedar	1	Young and Young 1992	Germination increases if the seed is stored.
Phacelia hastata Silverleaf phacelia	1e	Link 1993 Young and Young 1986	Fall seeding is recommended.
Phalaris arundinacea Reed canarygrass	1a	Young and Young 1986	The seed requires light to germinate. Reed canarygrass was native at the time of settlement, but is more widely distributed now as a cultivar. It is invasive.
Philadelphus lewisii Mock orange	1a: 56, 4	Rose and others 1998 Young and Young 1992	Stratify the seed at 41 degrees Fahrenheit (5 degrees Celsius) and 72 to 79 degrees Fahrenheit (22 to 26 degrees Celsius). Take softwood cuttings during June and July. Dip the cuttings in 1,000 parts per million indole-3-butyric acid (IBA) and stick them in a mixture of peat and perlite. Hardwood cuttings, about 8 inches (200 millimeters) long, can be taken during the fall or spring. Treat the cuttings with 2,500 to 8,000 parts per million IBA and plant them 6 inches (150 millimeters) deep in sandy soil. Plant the cuttings during the fall and apply mulch.
Phleum alpinum Alpine timothy	1a: 7	Weisberg 1993 **Link 1993** Rose and others 1998	Collect seed during August and September. Sow the seed during the fall or direct seed in April.
Phlox diffusa Phlox	2, **8**	Weisberg 1993 **Link 1993** Young and Young 1986	Plants are propagated by division in the nursery trade.
Photinia arbutifolia (See *Heteromeles arbutifolia*)			
Phyllodoce breweri Red mountain heather	1a: 56, 2	Link 1993	Keep the seed at 35 degrees Fahrenheit (2 degrees Celsius) for 2 months in moist

Scientific name Common name	Propagation method	References	Remarks
			vermiculite inside a sealed plastic bag. Results have been poor when red mountain heather has been propagated from cuttings.
Phyllodoce empetriformis Pink mountain heather	1, 2	Potash and Aubry 1997	Seed ripens from September 1 until the first snowfall. When the capsule is purplish-black, cut the branch tip with capsules and store it upside down in a paper bag. Seeds look like yellow dust. See additional information in appendix C.
Physocarpus capitatus Pacific ninebark	1, **3**, 4	**Rose and others 1998** Young and Young 1992	Seed ripens during August and September. Sow seed during the fall. Hardwood cuttings root better than softwood cuttings. Store the cuttings in sawdust and stick them into sand during late winter or early spring.
Physocarpus malvaceus Mallow ninebark	1, **3**, 4, 5	Link 1993 Rose and others 1998	Plant seed in containers during the fall or during the spring after seed has been chilled for 30 days. Mallow ninebark also can be propagated from root cuttings and rhizomes.
Picea spp. Spruce	1a: 21, 1e	**Young and Young 1992**	Do not sow Engelmann or blue spruce seed during the fall. Some species germinate better if the seed receives mild prechilling.
Picea breweriana Brewer spruce	1a: 16	Young and Young 1992	
Picea engelmannii Engelmann spruce	1a: 16	Young and Young 1992	Light is required for seed to germinate. Excessive moisture reduces survival. Use potassium nitrate (KNO_3) enrichment if the seed is dormant.
Picea pungens Colorado blue spruce	1a: 16	Young and Young 1992	Store seed at a constant temperature of 68 to 77 degrees Fahrenheit (20 to 25 degrees Celsius).
Picea sitchensis Sitka spruce	1a: 30, 1e	Rose and others 1998 Young and Young 1992	Seed will germinate better if it has been stratified. Sow seed 0.2 inch (5 millimeters) deep during the spring. Apply mulch. More than 8 hours of light may be beneficial.

Scientific name Common name	Propagation method	References	Remarks
Pinus spp.	1a: 60–252	Young and Young 1986	Soak the seed in water for 1 to 2 days, then stratify. Some species require a long stratification.
Pinus albicaulis Whitebark pine	1a: 90–120	Rose and others 1998	Collect cones when they turn dull purple to brown. Cones takes 15 to 30 days to dry and open. Stratify the seed by soaking it in water for 1 to 2 days before placing it in moist medium at 41 degrees Fahrenheit (5 degrees Celsius). Seed germinates poorly, but a small cut in the seed coat improves germination. Sow seed during the late fall or early spring, planting it ½ inch (13 millimeters) deep.
Pinus attenuata Knobcone pine	1a: 60	Young and Young 1992	Plant fresh seed directly or chill the seed before planting.
Pinus contorta Lodgepole pine	1a: 20–30	Young and Young 1992	Same as *Pinus attenuata*.
Pinus coulteri Coulter pine	1e	Harris and Leiser 1979	Direct seed during the fall.
Pinus flexilis White pine	1a: 90	Link 1993 Young and Young 1992	Soak the seed for 48 hours in water. Seed takes 90 days to germinate at 37 to 41 degrees Fahrenheit (3 to 5 degrees Celsius) in a moist mixture of peat and sand.
Pinus jeffreyi Jeffrey pine	1a: 0–60	Young and Young 1992	Direct seed during the fall or chill the seed before planting.
Pinus lambertiana Sugar pine	1a: 60–90	Young and Young 1992	Same as *Pinus jeffreyi*.
Pinus monophylla Single-leaf pinyon	1a: 28–90	Landis and Simonich 1983	Seed takes 8 to 12 months to grow.
Pinus monticola Western white pine	1a: 30–120	Young and Young 1992	Direct seed during the fall or chill the seed before planting.

Scientific name Common name	Propagation method	References	Remarks
Pinus ponderosa Ponderosa pine	1a: 30–40, 5, grafting	Rose and others 1998	Cold stratify stored seed. Sow seed during the late fall or spring about 0.2 inch (5 millimeters) deep.
Pinus radiata Monterey pine	1a: 0–7	Young and Young 1992	
Pleuraphis jamesii	1e	Young and Young 1986	
Poa alpina	1, 13	Densmore and others 1990	
Poa fendleriana Mutton grass	1e	Link 1993	
Poa nervosa Wheeler bluegrass	1e	Link 1993	
Poa scabrella Pine bluegrass	1a: 14	Rose and others 1998	Seed ripens from June to September. Prechill the seed before planting. Use potassium nitrate (KNO_3) and light for good germination. Keep temperature at 84 degrees Fahrenheit (29 degrees Celsius). Sow the seed in a mixture of peat and vermiculite (1:1). Grow for 3 months.
Poa secunda Sandberg bluegrass	1e	Rose and others 1998	Seed ripens during early summer. Plant the seed during the fall. Stratify at 54 degrees Fahrenheit (12 degrees Celsius) for 16 hours and 63 degrees Fahrenheit (17 degrees Celsius) for 8 hours. Do not plant the seed deeper than 1.2 inches (30 millimeters) in clay loam or sandy soil.
Polemonium occidentale Jacob's Ladder	1e	Link 1993	
Polygonum newberryi Newberry's fleece flower	1, **8**	Weisberg 1993 **Link 1993**	Divide sections of large root crowns with at least one visible bud. Seeding may be impractical due to limited availability of seed.
Polystichum munitum Sword fern	8	Weisberg 1993	

Scientific name Common name	Propagation method	References	Remarks
Populus spp.	1, 3, 4, 5	Weisberg 1993 **Young and Young 1992**	The seedlings are susceptible to drying, the washing action of rain or irrigation, and to damping off by fungi. A substrate that supplies moisture is critical for seedlings. Softwood and hardwood cuttings root readily. Take 12-inch (300-millimeter) cuttings from dormant 1-year-old wood.
Populus angustifolia Narrowleaf cottonwood	1, 2	Landis and Simonich 1983 Young and Young 1992	Start seed during the summer. Seedlings take 3 to 4 months to grow.
Populus deltoides Eastern cottonwood	3, 4, 5	Young and Young 1992	See *Populus* spp.
Populus tremuloides Quaking aspen	1, **5**	Landis and Simonich 1983 **Rose and others 1998**	Seed ripens from May to mid-June. Dry seed for 3 days at 75 degrees Fahrenheit (24 degrees Celsius). Sow seed on the surface of a moist seedbed at 59 to 77 degrees Fahrenheit (15 to 25 degrees Celsius). Start seed during the spring or summer. Seedlings take 3 to 4 months to grow. To propagate by rooting, collect lateral roots when the plant is dormant during early spring. Roots should be 0.4 to 0.8 inch (10 to 20 millimeters) in diameter and 1 inch (25 millimeters) long. Root in vermiculite for 6 weeks.
Populus trichocarpa Black cottonwood	1e, **2**, **4**	**Potash and Aubry 1997** Rose and others 1998	Seed ripens from May 15 to July 15 when capsules begin to open. Sow seed immediately, or dry the seed and store it. Cuttings should be 1 foot (310 millimeters) long or longer and from ½ to 1 inch (13 to 25 millimeters) in diameter. Cuttings can be rooted in water.
Porophyllum spp.	1	Young and Young 1992	Low seed viability. Storage increases viability slightly.
Potentilla arguta White cinquefoil	1	Link 1993	
Potentilla anserina Cinquefoil	8	Weisberg 1993	

Scientific name Common name	Propagation method	References	Remarks
Potentilla anserina Silverweed cinquefoil	1	Link 1993	
Potentilla flabellifolia Fan-leaf cinquefoil	1	Weisberg 1993	
Potentilla glandulosa Sticky cinquefoil	1	Link 1993	
Potentilla gracilis Northwest cinquefoil	1	Link 1993	
Prunus emarginata Bitter cherry	1a: 90–126, 1e, 4, 9	Young and Young 1992 **Rose and others 1998**	Direct seed during the fall, early enough to allow the seed to afterripen in the presence of oxygen and moisture before the ground freezes. The seed can be stratified at 41 degrees Fahrenheit (5 degrees Celsius) in a mixture of sand and peat before sowing during the spring.
Prunus ilicifolia Holly leaf cherry	1e	Harris and Leiser 1979	Direct seed during the fall.
Prunus subcordata Klamath plum	1a: 90	Young and Young 1992	Same as *Prunus ilicifolia*.
Prunus virginiana Choke cherry	1a: 120–160, 4, 5	Landis and Simonich 1983 Rose and others 1998	Seedlings take 3 to 5 months to grow.
Pseudotsuga macrocarpa Bigcone Douglas-fir	1a	Young and Young 1986	Bigcone Douglas-fir is native to coastal California. It is difficult to germinate.
Pseudotsuga menziesii Douglas-fir	1a: 30–40, 3	Rose and others 1998 Young and Young 1992	Collect cones from August to October when they are brownish purple. Use heat to dry the cones and open them. Sow the seed during the fall and allow it to stratify naturally over the winter or

Scientific name Common name	Propagation method	References	Remarks
			stratify the seed at 32 to 39 degrees Fahrenheit (0 to 4 degrees Celsius). Take cuttings from trees 9 to 12 years old or younger.
Psilostrophe spp.	1e	Young and Young 1992	The seed of *Psilostrophe* has poor rates of germination. Seed stored 1 year lost all viability.
Pteridium aquilinum Bracken fern	5	Potash and Aubry 1997	Collect rhizomes and plant them on the site during the fall.
Ptilagrostis kingii King's ricegrass	1	Link 1993	Keep seed moist and maintain temperatures of 65 to 70 degrees Fahrenheit (18 to 21 degrees Celsius) for germination.
Purshia glandulosa Desert bitterbrush	1a: 21–28	Young and Young 1992	Stratify seed at 32 to 41 degrees Fahrenheit (0 to 5 degrees Celsius).
Purshia tridentata Antelope bitterbrush	1a: 60–90, 4, 11	Landis and Simonich 1983 Shaw 1983 Rose and others 1998 Young and Young 1992	Seed ripens from June 25 to August 15. Treat seed with Captan or with 3-percent hydrogen peroxide for 5 hours to enhance germination. Plant seed during the fall. Seedlings take 4 to 8 months to grow. To propagate with cuttings, collect cuttings that are 4 inches (100 millimeters) long during June. Root cuttings in a mixture of sand, pumice, and vermiculite. To propagate by layering, bend a branch into a small hole beside the plants, keeping the tip of the branch vertical and above the soil level. Cover with soil. This plant fixes nitrogen.
Pyrus spp. (See *Malus* spp.)			
Quercus agrifolia Coast live oak	1e	Harris and Leiser 1979	Direct seed during the fall.
Quercus chrysolepis	1a: 0–60	Young and Young 1992	

Scientific name Common name	Propagation method	References	Remarks
Quercus douglasii Blue oak	1e	Harris and Leiser 1979 Young and Young 1992	Direct seed during the fall.
Quercus dumosa Scrub oak	1a: 30–90	Harris and Leiser 1979 **Young and Young 1992**	Direct seed during the fall.
Quercus durata Leather-leaf oak	1e	Harris and Leiser 1979	Direct seed during the fall.
Quercus gambelii Gambel oak	1	Landis and Simonich 1983	Start seed during the fall. Seedlings take 6 to 8 months to grow.
Quercus garryana Oregon white oak	1e	Rose and others 1998 Young and Young 1992	Soak fresh acorns overnight. Plant the acorns ½ inch (13 millimeters) deep during the fall. Fresh acorns germinate rapidly.
Quercus kelloggii California black oak	1a: 30–45, 1e	Harris and Leiser 1979 Rose and others 1998 Young and Young 1992	Direct seed during the fall. Plant seed immediately or store the seed and stratify it at 34 to 41 degrees Fahrenheit (1 to 5 degrees Celsius) before planting the seed during the spring.
Quercus lobata Valley oak	1e	Harris and Leiser 1979	Direct seed during the fall.
Rhamnus alnifolia Alder buckthorn	1e, 3, 4	Young and Young 1992	Direct seed during the fall.
Rhamnus californica California buckthorn	1e, 3, 4	Harris and Leiser 1979 Young and Young 1992	Direct seed during the fall.
Rhamnus crocea Redberry	1e, 3, 4	Young and Young 1992	Direct seed during the fall.
Rhamnus purshiana Cascara buckthorn	1e, 1a: 90–115, 3, 4, 9	Rose and others 1998 Young and Young 1992	Seed ripens from July through September. Pick fruit before it is fully ripe. Macerate the fruit and separate the seed using flotation.

Scientific name Common name	Propagation method	References	Remarks
			Plant seed during the fall or stratify seed at 34 to 41 degrees Fahrenheit (1 to 5 degrees Celsius) before sowing it during the spring. Take hardwood cuttings during September and October. Propagate by layering during the early spring.
Rhododendron spp.	1e, 9, 11 (spring/ summer)	Weisberg 1993 Young and Young 1992	Seed needs light to germinate.
Rhododendron albiflorum White-flowered rhododendron	5, 9	Rose and others 1998	Most rhododendrons do not require prechilling or scarification, but they do need light to germinate.
Rhododendron macrophyllum Pacific rhododendron	1, 4, 7, 9	Weisberg 1993 **Rose and others 1998**	Collect the seed as soon as the fruit loses its color. Mix seed with fungicide and sow on a mixture of peat and perlite. Cover the flat with glass or plastic. Or sow the seed on screened coarse peat, leaving the flat uncovered while providing bottom heat. Treat with fungicide weekly. The seed needs light to germinate. Take stem cuttings from current growth from May to September. Soak 1.5 to 3 inches (38 to 76 millimeters) of the cutting in benomyl. Wound lower 0.4 to 0.8 inch (10 to 20 millimeters) of the cutting to expose the cambium. Dip the cutting into 0.1- to 1.6-percent indole-3-butyric acid (IBA). Root in a mixture of peat and perlite. Apply bottom heat. When the root ball is 1.2 to 2 inches (30 to 50 millimeters) in diameter, transplant cuttings to a mixture of sawdust and peat. Move the cuttings outdoors to harden them during the early summer.
Rhus spp.	5	Weisberg 1993	
Rhus aromatica Fragrant sumac	1a: 30–90, 1d	Young and Young 1992	Scarify the seed with acid or hot water to break the hard seed coat.
Rhus glabra Smooth sumac	1d, 5	Rose and others 1998 Young and Young 1992	Pick the fruit late in the year. Soak seed in sulfuric acid for 1 to 3 hours. Keep seed in continuous light at a temperature of 68 degrees

Scientific name Common name	Propagation method	References	Remarks
			Fahrenheit (20 degrees Celsius) to promote germination. Sow the seed during the spring.
Rhus trilobata Skunkbush sumac	1a: 30–90, 1d	Landis and Simonich 1983 Young and Young 1992	Seed ripens from June 20 to October 10. Start seed during the fall. Seedlings take 4 to 6 months to grow.
Ribes spp.	1, 2, 3, 5, 10 (spring)	Weisberg 1993	
Ribes cereum Squaw currant	1a: 84–119, 1b, 3	Link 1993 **Rose and others 1998**	Seed ripens during August. Scarify and stratify the seed. Take hardwood heel cuttings during June. Dip cuttings into 0.8-percent indole-3-butyric acid (IBA).
Ribes erythrocarpum Crater Lake currant	1a: 120, 3	Link 1993	Cuttings do poorly. Stratified seed produces a high percentage of healthy plants.
Ribes lacustre Black gooseberry	1a: 120–200, 1d, 3, 9	**Rose and others 1998**	Fruit ripens during August. Extract the seed immediately. Sow the seed during the spring after stratifying it at 32 degrees Fahrenheit (0 degrees Celsius). Soaking the seed for 5 minutes in 2 to 10 percent sulfuric acid can improve germination. Sow the seed during the fall. Take 6- to 8-inch (150- to 200-millimeter) cuttings from 1-year-old wood during the fall.
Ribes montigenum Sierra gooseberry	1a	Link 1993	
Ribes viscosissimum Sticky currant	1a	Link 1993	Cuttings do poorly.
Robinia spp. Locust	1b, 5	Weisberg 1993 **Young and Young 1986**	Scarify the seed mechanically, with acid, or by soaking in boiling water. Plant seed ½ inch (13 millimeters) deep and mulch lightly.
Rosa spp. Wildrose	1, **2**, 3, 4, 9, 12	Hartmann and others 1990 Weisberg 1993	Separate the seed from the fruit by flotation. Outplant seedlings in late spring or early summer.

Scientific name Common name	Propagation method	References	Remarks
Rosa gymnocarpa Baldhip rose	1a: 90, 1e, 2	Rose and others 1998 Young and Young 1992	Pick red hips during August and September. Macerate the hips and use flotation to separate the seed. Germination is best when the seed is sown after cleaning. Stratify stored seed at 34 to 37 degrees Fahrenheit (1 to 3 degrees Celsius). When taking cuttings, include three to four nodes. Use root hormone.
Rosa nutkana Nootka rose	1f, 1e	Rose and others 1998 Young and Young 1992	Seed ripens during August and September. Clean the seed, which requires a period of afterripening. If the seed is sown during the spring, stratify the seed warm then cold. Sow fresh seed during the fall into a finely milled mixture of peat and vermiculite.
Rosa pisocarpa Cluster rose	1f	Rose and others 1998	Soak the hips in water for 5 to 7 days in a warm place before macerating the hips and floating away the pulp. During the fall, seed can be sown into a standard potting mixture and left outside over winter. Stratify the seed warm and cold if it will be sown during the spring.
Rosa woodsii Wood's rose	1f: cold 84/168, 4, 8, 9	Landis and Simonich 1983 **Rose and others 1998** Young and Young 1992	Sow fresh seed during the fall. If the seed will be sown during the spring, stratify it warm to cold at 39 degrees Fahrenheit (4 degrees Celsius). To propagate from cuttings, take 6-inch (150-millimeter) softwood cuttings during mid to late June. Wood's rose spreads by rhizomes.
Rubus spp.	12 (summer)	Weisberg 1993	
Rubus idaeus Red raspberry	1b, 1f: 90/90, 5, **8**, 9	Rose and others 1998 Young and Young 1992	Use flotation to separate the seed. Germination is best when the seed is scarified and sown during the fall. Scarify the seed in sulfuric acid for 20 to 60 minutes or in a 1-percent solution of sodium hyperchlorite for 7 days. If the seed will be sown during the spring, it should be stratified warm at 68 to 86 degrees Fahrenheit (20 to 30 degrees Celsius) and cold at 36 to 41 degrees Fahrenheit (2 to 5 degrees Celsius). Lightly cover the seed with soil. Take root cuttings when the plants are dormant.

Scientific name Common name	Propagation method	References	Remarks
Rubus lasiococcus Dwarf bramble	2, 5, **8**	Potash and Aubry 1997 Rose and others 1998	Fruits ripen from July 1 to September 30. Dwarf bramble can be propagated easily from runners.
Rubus leucodermis	5	Weisberg 1993	
Rubus nigerrimus	5	Weisberg 1993	
Rubus parviflorus Thimbleberry	1e or 1f: 90/90	**Potash and Aubry 1997** Rose and others 1998	Seed ripens from June 1 to September 30 when the berry is red. Process the berries immediately by macerating them and using flotation to separate the seed. Seed may not need treatment, but can be stratified for 90 days at 68 to 86 degrees Fahrenheit (20 to 30 degrees Celsius), then for 90 days at 36 to 41 degrees Fahrenheit (2 to 5 degrees Celsius). A sulfuric acid treatment before the cool stratification may increase germination.
Rubus pedatus Strawberry bramble	1, 2, 8	Weisberg 1993 Potash and Aubry 1997	Same as *Rubus lasiococcus*.
Rubus spectabilis Salmonberry	1f: 90/90, 3, 5, 8, 12	**Potash and Aubry 1997** Rose and others 1998 Young and Young 1992	Berries ripen from June 15 to September 30 when they are orange or red. Process the berries and treat them as recommended for *Rubus parviflorus*. Small offshoots can be transplanted. Hardwood cuttings will be ready for planting in 4 months. Use liquid rooting hormone and bury the cuttings in damp wood shavings.
Rubus ursinus Pacific blackberry	2, 5, 7, 9	Weisberg 1993 **Potash and Aubry 1997** Rose and others 1998	Berries ripen from June 1 to August 30 when they turn black. Process the berries and treat them as recommended for *Rubus parviflorus*. One vine can be used to make a number of cuttings.
Salazaria mexicana Bladder sage	1e	Young and Young 1992	
Salix spp. Willow	3, 9 (spring)	Weisberg 1993	Willow species are difficult to tell apart. Collect them from the appropriate habitat.

Scientific name Common name	Propagation method	References	Remarks
Salix alaxensis	1, **cuttings**	Densmore and others 1990	
Salix bebbiana Bebb willow	1e, 2, 3, 5, 9	Rose and others 1998 Young and Young 1992	It is not necessary to separate the seed from the capsule. Seed is viable just for a few days. Sow the capsules on beds, keeping them moist. To propagate Bebb willow from cuttings, take 12-inch (300-millimeter) cuttings from 1-year-old wood during the late fall or early spring. Plant the cuttings in heavy damp soil.
Salix lasiandra Pacific willow	1e, 2, 3	Rose and others 1998 Young and Young 1992	Sow seed in flats with a mixture of sand, perlite, peat, and vermiculite. Take cuttings from 1- to 4-year-old wood during the middle of the fall to early spring. The terminal end should be cut horizontally and the basal end should be cut at 45 degrees. Apply fungicide. Cuttings can be planted directly on the site.
Salix orestera Sierra willow	3	Link 1993	Transplant cuttings into cone cells with a medium of perlite, peat, vermiculite, sand, and Osmocote. Keep the cuttings moist with 70-degree-Fahrenheit (21-degree-Celsius) bottom heat. Place the cuttings in a lathhouse for the entire winter.
Salix scouleriana Scouler's willow	1e, **3**, **4**	**Potash and Aubry 1997** Rose and others 1998 Young and Young 1992	Seed ripens from April 1 to July 30 soon after flowering. Sow the seed immediately, or store moist seed for up to 30 days. To propagate Scouler's willow from cuttings, take softwood cuttings 1 foot (300 millimeters) long or hardwood cuttings 3 feet (910 millimeters) long, and cut them into 6-inch (150-millimeter) whips. This is an upland species. Cuttings should not be used for bioengineering applications, such as live stakes.
Salix sitchensis Sitka willow	1e, 4, **live stakes**	**Potash and Aubry 1997**	Collect and handle the seed as recommended for *Salix scouleriana*. To propagate Sitka willow from cuttings, take softwood cuttings 1 foot (300 millimeters) long when the plant is dormant. These cuttings can be used as live stakes for bioengineering applications.

Scientific name Common name	Propagation method	References	Remarks
Salvia leucophylla Purple sage	1e	Harris and Leiser 1979	Direct seed during the fall.
Salvia lyrata Lyre-leafed sage	1e	Link 1993	Broadcast seed at a rate of 3 to 4 pounds per acre (3.4 to 4.5 kilograms per hectare) during the early summer. Seed shatters easily.
Salvia sonomensis Creeping sage	1a	Young and Young 1992	Chill the seed before planting.
Sambucus spp.	9 (spring)	Weisberg 1993	
Sambucus canadensis Elderberry	1e	Link 1993	Seed ripens from June to September. Add some water before depulping the fruit in a blender. Plant the seed during the fall.
Sambucus cerulea Blue elderberry	1f: 60–90/90–112, 3	Landis and Simonich 1983 **Rose and others 1998** Young and Young 1992	Collect the seed and sow it during the fall. If the seed can't be planted after it is collected, stratify it with 8 hours of light daily. During the winter, take hardwood cuttings with a heel from the previous season's growth.
Sambucus racemosa Red elderberry	1c, d, then f: 70/84 2, 3, 4	Weisberg 1993 **Potash and Aubry 1997** Rose and others 1998	Berries ripen from July 1 to September 30 when they are red. Macerate the fruit and separate the seed using flotation. Provide light 8 hours per day for germination. Tip cuttings or side-shoot cuttings from pruned plants are the easiest cuttings to handle. Cuttings grow quickly. Outplant the cuttings early enough so they can become established before winter.
Sapindus drummondii Western soapberry	1a: 90, 1d	Link 1993 **Young and Young 1992**	Scarify the seed in acid for 2 to 2½ hours. Freshly collected seed germinates better than seed that has been dried.
Sarcobatus vermiculatus Greasewood	1	Young and Young 1986	Remove the seed from the fruit for best results.
Satureja douglasii Yerba Buena	1e	Young and Young 1986	

Scientific name Common name	Propagation method	References	Remarks
Saxifraga ferruginea Rusty saxifrage	6	Weisberg 1993	
Saxifraga tricuspidata	1	Densmore and others 1990	
Schinus molle California pepper tree	1e	Harris and Leiser 1979	Direct seed during the fall.
Senecio lugens	1	Densmore and others 1990	
Sequoia sempervirens Redwood	1e	Young and Young 1992	Sow seed during the spring when frost is not likely and soil temperatures are warm. Thin seedlings to 315 per 11 square feet (1 square meter) of seedbed. Keep seedlings in half shade.
Sequoiadendron giganteum Giant sequoia	1a: 60	Young and Young 1992	Soak seed overnight in distilled water, then stratify. Sow seed during the spring.
Setaria macrostachya Bristly foxtail	1b	Young and Young 1986	Scarify seed in acid for 15 to 30 minutes. This seed requires a prolonged afterrripening.
Shepherdia argentea Silver buffaloberry	1a: 0–90, **5**, 9	Landis and Simonich 1983 **Rose and others 1998** Young and Young 1992	Fruit ripens from June to August. Macerate the fruit and separate the seed using flotation. Scarify and stratify the seed. To propagate silver buffaloberry from cuttings, stick root cuttings into ordinary outside soil during February or March. Layer shoots during the fall.
Shepherdia canadensis Russet buffaloberry	1a: 60–90, 1d	Densmore and others 1990 **Young and Young 1992**	Scarify seed with acid before stratifying it. Sow seed during the fall or spring. This species is subject to greenhouse pathogens.
Silene spp.	1	Young and Young 1986	The seed needs light to germinate.
Silene acaulis	1	Densmore and others 1990	
Simmondsia chinensis Jojoba	1e, 4	Harris and Leiser 1979	Direct seed during the fall. Plant the seed 1.6 to 2 inches (40 to 50 millimeters) deep. Take

Scientific name Common name	Propagation method	References	Remarks
		Young and Young 1992	cuttings during the late spring or early summer.
Sitanion hystrix Squirreltail	1e	Young and Young 1986	
Smilacina racemosa False Solomon's-seal	1, 8, rhizomes	Rose and others 1998	The seed has double dormancy and requires 2 years to germinate. Sow during the fall in a shady, moist area. Propagate by divisions during the fall or early spring.
Solidago canadensis Canada goldenrod	1e, 8, 13	Link 1993	Seed ripens from mid-August to late October. Broadcast the seed. Plants can be divided and transplanted during the fall or spring.
Solidago multiradiata	1	Densmore and others 1990	
Sophora spp.	1b	Young and Young 1992	Scarify the seed with acid or mechanical scarification.
Sorbus scopulina Green mountain ash	1e, 2	Link 1993	
Sorbus sitchensis Sitka mountain ash	1a: 90–140, 1e	Potash and Aubry 1997 **Rose and others 1998**	Berries ripen from August 1 to October 31 when they are dark red. If the berries are collected early, keep them in heaps for 2 months so they can decompose. Macerate the fruit and separate the seed using flotation. Seed may take 2 years to germinate. Sow seed during the fall or early winter. If seed will be sown during the spring, stratify it at 34 to 41 degrees Fahrenheit (1 to 5 degrees Celsius) in moist peat. Use drills to sow cleaned seed. This species is difficult to start from cuttings.
Spirea betulifolia Birchleaf spirea	1e, 4, 8, 9	Rose and others 1998 Young and Young 1992	Seeds disperse during October. Seed can be sown during the fall and allowed to overwinter. Take cuttings during mid-June. Dip the cuttings in 3,000-parts-per-million indole-3-butyric acid (IBA) talc before sticking the cuttings into sand in an outdoor frame and applying bottom heat.

Scientific name Common name	Propagation method	References	Remarks
Spirea densiflora Subalpine spirea	**1e or 1a: 30–60** 2, 3, **4**, **8**	Potash and Aubry 1997 Rose and others 1998	Seed ripens from September 15 to November 15 when the capsule turns brown. Flower heads can be collected earlier and allowed to ripen in paper bags. Softwood cuttings can be taken at any time that the branches have leaves.
Spirea douglasii Hardhack or Douglas spirea	**1e**, **2**	**Potash and Aubry 1997** Rose and others 1998	Dry seed may require 1 to 2 months of cold before germination. Sow ¼ teaspoon (1.2 milliliters) of seed per flat during February or March. Cuttings should be taken during the fall from softer wood. They will root in 2 to 4 weeks and can be transplanted immediately. Be wary of aphids, leaf rollers, and fire blight.
Spirea splendens Alpine spirea	1a: 48, 2	Link 1993	Seed ripens from the end of August through September. Direct seed into containers, or root cuttings from 1-year-old wood using a mist bench. Cuttings should be taken from active wood during the summer.
Sporobolus airoides Drop seed	1a: 5	Young and Young 1986	
Sporobolus giganteus	1a: 5	Young and Young 1986	
Stanleya spp. Prince's plum	1e	Young and Young 1992	
Staphylea spp. Bladdernut	1b, 1f: 84/84	Young and Young 1992	Seed requires scarification with acid.
Stephanomeria pauciflora	1	Young and Young 1992	Germination increases if the seed is stored.
Stipa lemmonii Lemmon needlegrass	1a	Rose and others 1998	Seed ripens during early June. Cold stratify the seed in potassium nitrate and gibberellic acid and plant it in 3-cubic-inch (49-cubic-centimeter) containers with a 1:1 mixture of peat and vermiculite. Apply a low-nitrogen fertilizer once a week.

Scientific name Common name	Propagation method	References	Remarks
Stipa nelsonii Columbian needlegrass	1e	Link 1993	Germination was higher when the seed was started in a lathhouse rather than a greenhouse. Use misters and keep temperatures between 65 and 70 degrees Fahrenheit (18 and 21 degrees Celsius).
Stipa occidentalis Western needlegrass	1e	Link 1993	Seed ripens during late August to early September. Sow the seed during the fall in media amended with peat and slow-release fertilizer. Direct seed about 5 to 8 seeds in each container. Chill the containers outside for a week, then put them in a greenhouse.
Stipa richardsonii Richardson needlegrass	13	Link 1993	Seed ripens from mid-July to mid-August. Apply seed directly and mulch with forage harvested when the seed heads mature.
Streptopus spp. Twisted stalk	8	Weisberg 1993	
Styrax officinalis Snowdrop bush	1a: 60	Young and Young 1986	
Symphoricarpos spp.	1f, 8, root suckers	Hartmann and others 1990	Use flotation to separate the seed from the fruit. Stratify the seed with 90 to 120 days of warm and moist conditions, followed by 180 days at 41 degrees Fahrenheit (5 degrees Celsius).
Symphoricarpos albus Snowberry	**1f: 60 days at room temperature/180 days at 5 degrees Celsius**, 2, 3, 4, 5, 8	Weisberg 1993 Potash and Aubry 1997 **Rose and others 1998** Young and Young 1992	Extract the seed by running berries through a macerator with water. Seed is difficult to germinate. Keep seed at room temperature for 3 to 4 months, then at 41 degrees Fahrenheit (5 degrees Celsius) for 4 to 6 months. This species develops powdery mildew.
Symphoricarpos occidentalis Western snowberry	1f, 1b	Young and Young 1992	Seed requires acid scarification for 20 to 75 minutes. Seed should be stratified warm for 90 to 120 days before sowing in the fall.

Scientific name Common name	Propagation method	References	Remarks
Symphoricarpos oreophilus Mountain snowberry	1a: 60–300, 8, 9	Landis and Simonich 1983 Rose and others 1998	Seed has double dormancy and may need to be soaked in hot water before planting. Sow stratified seed during the spring or unstratified seed during the fall. Keep the seed moist after planting.
Taxus brevifolia Pacific yew	3	Weisberg 1993	
Tetracoccus hallii	1e	Young and Young 1992	The germination rate is about 50 percent. Seed can be stored for up to 2 years.
Tetradymia canescens Horsebrush	1a: 28–52	Young and Young 1992	
Thalictrum spp. Meadow rue	1e, 8	Weisberg 1993 Young and Young 1986	
Thalictrum fendleri Fendler meadow rue	1	Rose and others 1998	Place seed under running water for 4 hours. Stratify in a dilute solution of gibberellic acid on double layers of filter paper. Temperatures should be 72 degrees Fahrenheit (22 degrees Celsius) for 8 hours (with light) and 63 degrees Fahrenheit (17 degrees Celsius) for 16 hours (without light).
Thuja plicata Western red cedar	1a: 30–40, 1e, 3, 9	Weisberg 1993 Rose and others 1998 Young and Young 1992	Cones ripen during early August, turning yellow to brown. Dry the cones. Stratify stored seed at 34 to 37 degrees Fahrenheit (1 to 3 degrees Celsius). Sow seed during the spring, 0.2 inch (5 millimeters) deep. Keep seedlings shaded for the first year.
Tolmiea menziesii Piggyback plant	6	Weisberg 1993	
Torreya californica California nutmeg	1e	Young and Young 1992	The seed requires a long period of afterripening. Germination takes several months.
Trifolium spp. Clover	1b	Young and Young 1986	Ethylene or carbon dioxide enrichment is recommended.

Scientific name Common name	Propagation method	References	Remarks
Trisetum spicatum	1a	Young and Young 1986	Seed requires light to germinate.
Tsuga spp. Hemlock	9 (spring)	Weisberg 1993	
Tsuga heterophylla Western hemlock	1a: 21–90, 2, 9, grafting	Rose and others 1998 Young and Young 1992	Collect cones from the tree and air-dry them. Soak the seed in cold water for 24 to 26 hours. Stratify the seed before sowing it on the surface during the spring.
Tsuga mertensiana Mountain hemlock	1a: 90	Young and Young 1992	Do not chill the seed too long or it will be damaged.
Umbellularia californica Myrtlewood	1e, cuttings	Young and Young 1992	Collect the fruit during the late fall. Macerate the fruit and separate the seed with flotation. Seeds loses viability rapidly. Seedlings take several months to emerge.
Vaccinium spp.	10 (spring)	Weisberg 1993	
Vaccinium caespitosum Dwarf blueberry	2	Link 1993 Young and Young 1992	
Vaccinium deliciosum Cascade blueberry	1, 3, 4	Weisberg 1993 **Rose and others 1998**	Seed ripens during the late summer to early fall. Macerate the fruit, then separate the seed using floatation. Sow seed on a bed of moist peat. Ideal temperatures are 65 degrees Fahrenheit (18 degrees Celsius) during the day and 55 degrees Fahrenheit (13 degrees Celsius) during the night. Seven weeks after germination, increase temperatures to 68 degrees Fahrenheit (20 degrees Celsius) during the day and 52 degrees Fahrenheit (14 degrees Celsius) during the night. To propagate Cascade blueberry from cuttings, take 6-inch (150-millimeter) hardwood cuttings during January or February from 2-year-old wood. Plant the cuttings horizontally about 1 inch (25 millimeters) deep in a mixture of peat and sand. The cuttings will be ready to plant by the following winter or spring. Take 4-inch (100-millimeter) softwood heel cuttings as soon as new growth gets woody (from mid-June to July). Transplant cuttings to a nursery bed around the end of October. Outplant 1 year later.

Scientific name Common name	Propagation method	References	Remarks
Vaccinium membranaceum Mountain huckleberry	1e, 5	Link 1993 **Rose and others 1998**	Seed ripens during August. Overwinter in flats. Seed germinates best on moist peat at temperatures of 64 degrees Fahrenheit (18 degrees Celsius) for 12 hours and 55 degrees Fahrenheit (13 degrees Celsius) for 12 hours. Seven weeks after germination, increase the temperatures to 68 degrees Fahrenheit (20 degrees Celsius) and 57 degrees Fahrenheit (14 degrees Celsius). Take 4-inch (100-millimeter) cuttings from rhizomes during the early spring, late summer, and fall.
Vaccinium occidentale Western blueberry	1a: 90	Sheat 1948 Dirr and Heuser 1987	Use a lime-free potting mix. Sow seed during the late winter in a greenhouse. Just cover the seed with potting mix. The seed might require up to 3 months cold stratification. Once seedlings are about 2 inches (10 millimeters) tall, replant the seedlings in individual pots and grow them in a lightly shaded portion of the greenhouse, at least for their first winter.
Vaccinium parvifolium Red huckleberry	1, 2	Weisberg 1993 Potash and Aubry 1997 Rose and others 1998 Young and Young 1992	Use a blender to separate the seed. Float off the pulp. Seed should be chilled at 50 degrees Fahrenheit (10 degrees Celsius) for several days. Dry seed at 59 to 70 degrees Fahrenheit (15 to 21 degrees Celsius) for 2 days. Stored seed germinates well when kept at 82 degrees Fahrenheit (28 degrees Celsius) in the light for 14 hours and at 55 degrees Fahrenheit (13 degrees Celsius) in the dark for 10 hours. Take cuttings when the plants are dormant.
Vaccinium scoparium Grouse whortleberry	1e, 2, 5	Link 1993 Rose and others 1998	After collecting seed, place it in a plastic bag and store it at 41 degrees Fahrenheit (5 degrees Celsius) for a few days to a few weeks. Macerate the fruit, separate the seed using floatation. Seed does not require treatment before planting.
Vaccinium uliginosum occidentale Western blueberry	2	Link 1993	Transplant cuttings into cone cells with a mixture of perlite, peat, vermiculite, sand, and Osmocote. Apply bottom heat of 70 degrees Fahrenheit (21 degrees Celsius). Keep the medium moist. Place in a lathhouse for winter.

Scientific name Common name	Propagation method	References	Remarks
Valeriana sitchensis Sitka valerian	8	Weisberg 1993	
Vancouveria sitchensis Inside-out flower	8	Weisberg 1993	
Veratrum californicum False hellebore	1: 48–84	Link 1993 Young and Young 1986	False hellebore has a very low germination rate. Seed production is inconsistent from year to year.
Verbena spp.	1e	Young and Young 1986	*Verbena* requires light for germination.
Viburnum spp.	1, 3, 4	Young and Young 1992	Seed can be sown in nursery beds during the spring for warm stratification. By the following winter, the seed will be chilled. Seedlings will emerge the next spring. This species can be propagated with softwood or hardwood cuttings and with air layering.
Viburnum edule Highbush cranberry	1f, 2, 4, 9	Rose and others 1998	Seeds are difficult to germinate because of their hard seed coat and embryo dormancy. Take cuttings from 1-year-old and new growth during July and August.
Viburnum ellipticum Western viburnum	1f, 2, 4, 9	Randall and others 1978	
Vicia americana American vetch	1e	Rose and others 1998	Seed ripens during September. Seed should be at least 1 year old. Plant during the spring or fall in moist, clay soil.
Viguiera multiflora Showy goldeneye	1e	Link 1993	Seed ripens from early to mid-September. Dormant fall seeding is recommended. Seed should be broadcast.
Viola spp.	1e	Young and Young 1986	
Washingtonia filifera California fan palm	1e	Young and Young 1992	Macerate the fruit and float off the seed. Do not allow the seed to dry. Do not store the seed for a long time. Sow the seed in sand or a mixture

Scientific name Common name	Propagation method	References	Remarks
			of peat and sand. Apply bottom heat. Transplant seedlings to containers once the elongated second leaf appears. Grow seedlings in partial shade.
Wyethia amplexicaulis Mule's ear	1a: 28	Rose and others 1998 Young and Young 1986	Seed ripens during July and August.
Yucca baccata Spanish bayonet	1e	Link 1993	Sow seed directly into the final containers. Soak the seed for 24 hours or scarify the seed mildly.
Yucca elata Soaptree yucca	1b	Young and Young 1992	Soak the seed for 24 hours or scarify the seed mildly.
Yucca glauca Yucca	1, 2, 5, 8, rhizomes	Link 1993 Young and Young 1992	Soak seed for 24 hours or mechanically scarify the seed to remove its hard seed coat. Seedlings should be ready for transplanting during the second season. Yucca can be propagated by root cuttings covered with 4 inches (100 millimeters) of soil.
Xerophyllum tenax Beargrass	1e or 1a: 180 8	Potash and Aubry 1997	The seed requires no treatment for sowing during the fall. If the seed will be sowed during the spring, store flats of covered seed outside in a sheltered location until spring. Uncover the flat and add a layer of dry perlite. See additional information in appendix C.

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Appendix C—Detailed Propagation Methods for Beargrass, Heather, Huckleberry, and Partridgefoot

Beargrass (*Xerophyllum tenax*)

According to the literature reviewed, two methods were found to propagate seed from the coarse evergreen perennial, *Xerophyllum tenax* (figures C–1a and 1b):

Figure C–1a—Beargrass, *Xerophyllum tenax*, is a dominant and durable species in many mountainous areas throughout the Pacific Northwest, making it a desirable restoration species. Drawings courtesy of the University of Washington Press (Hitchcock and Cronquist 1976).

Figure C–1b—Beargrass blossoms brighten alpine meadows during early summer.

Method A (From the University of Idaho Forest Research Nursery)

Begin by soaking the seed in a running water bath for imbibition (when the seed absorbs water and swells). Sow the seed into copper-treated styrofoam blocks called Copperblock (45-cell, 12-ounce [340-milliliter] trays) (Silvaseed Co., Roy, WA) in a medium of 50-percent peat moss and 50-percent vermiculite, along with a top covering of No. 2 nursery grit.

Saturate the medium with water and place all trays in a walk-in cooler for a cold stratification period of 7 months at 31 to 42 degrees Fahrenheit (–0.6 to 5.5 degrees Celsius). After this cold stage, place all trays into a greenhouse with temperatures between 70 and 81 degrees Fahrenheit (21 and 27 degrees Celsius). Some seed may have begun to germinate at this point. After 8 weeks, thin and consolidate the seedlings, leaving four or five plants per cell in the Copperblock trays. These plants will create enough root mass to fill each 12-ounce (340-milliliter) cell by the end of the 7-month growing season.

Provide 24-hour lighting in the greenhouse with a 500-watt halogen light, suspended 6 feet (1.8 meters) above the plants. Fertilize plants twice weekly 3 weeks after germination with Peter's 7–40–17 Conifer Starter (42 parts per million of nitrogen). Increase the nitrogen at 7 weeks, using Peter's 20–7–19 Conifer Grower (192 parts per million of nitrogen) and CAN 17 calcium nitrate (162 parts per million of nitrogen) once a week.

Six weeks before outplanting, turn off extra lights to begin hardening off the seedlings. Taper off watering slightly. After each mild moisture stress, apply Peter's 4–25–35 Conifer Finisher (24 parts per million of nitrogen), alternating with calcium nitrate (51 parts per million of nitrogen). Move the seedlings to an outside shadehouse for further hardening 1 month before planting. Maintain the same fertilization regime during this period.

After this process, all seedlings should be at least 6 inches (150 millimeters) tall with ample root growth. To transport seedlings into the backcountry, cover their roots with a plastic bag to keep them moist and pack them in cardboard boxes. Separate seedlings with enough paper to eliminate shifting.

Method B (From the Olympic National Park Greenhouse)

For fall sowing, collect seed and sow directly.

For spring sowing, two methods have been successful:

- Soak the seed in distilled water for 24 hours, sow in flats of vermiculite, cover with vemiculite, and keep moist. Cold stratify for 112 days at 37 degrees Fahrenheit (3 degrees Celsius). After this period, place the flats in a growth chamber at 64 degrees Fahrenheit (18 degrees Celsius) for 12 hours during the day and 55 degrees Fahrenheit (13 degrees Celsius) for 12 hours at night.
- Soak the seed in distilled water for 24 hours, sow in flats of peat/vermiculite/perlite/pumice medium (2:2:2:1), and keep moist. Cover flats with a cloth that is permeable to water and air and place them outside in a sheltered place until the spring. Uncover the flats before germination in the spring. Move them into a warm spot in the greenhouse when germination begins. Because the seedlings are susceptible to damping off, keep a dry layer of perlite on the surface of the flats.

Transplant seedlings into deep pots with well-drained planting medium and cover the seedlings with a thin layer of perlite to prevent crown rot. When transplanting new plants, be careful not to injure young roots at the base of the crown.

(Olympic National Park Greenhouse cited in: Rose, R.; Chaculski C.E.C.; Haase, D. 1998. Propagation of Pacific Northwest native plants. Corvallis, OR: Oregon State University Press: 60–61.)

Propagation of Red Mountain-Heather (*Phyllodoce empetriformis*) and White Mountain-Heather (*Cassiope mertensiana*) in the Olympic Mountains

Seed Collection and Propagation

The date of snow release varies annually for *Phyllodoce empetriformis* (figure C–2), but usually occurs between mid-June and mid-July. In the Olympic Mountains, Olmsted (1975) found that the number of days between snow release and flowering varied from 21 to 35 in two succeeding years. About 45 days from flower wilting until seed shedding is typical. Seed collections should take place from early September until snowfall.

Figure C–2—Red mountain heather (*Phyllodoce empetriformis*). Drawings courtesy of the University of Washington Press (Hitchcock and Cronquist 1976).

When the capsules (which are umbellike and borne terminally) change color, the seed has reached maturity. Capsules turn from yellow-green to red as they swell and darken to purplish-black. In mid- to late-September, capsules dehisce at the apex and the minute seeds are dispersed by the wind. Before seed dispersal, entire inflorescences can be detached with the stem tips and stored in paper bags.

Because the capsules of *Phyllodoce empetriformis* dehisce from the apex, if the inflorescences have been stored upside down, the seeds will drop to the bottom of the bag in a few weeks, where they will look like fine, yellow-brown dust. Seeds of this species are tiny—about 0.04 inch (1 millimeter) in diameter. Batches of pure seed can be gathered by sifting the contents of the bag through a No. 30 screen. The inflorescences can be abraded over the screen to dislodge the remaining seeds from the capsules.

Olmsted (1975) concluded that stratification of seeds at 39 degrees Fahrenheit (4 degrees Celsius) for 14 days enhanced germination by 20 percent. We have seen prolific germination with seed lots stored dry in polyethylene bags at low temperatures. Cold, moist stratification is probably not necessary for this species. As with many subalpine and alpine species, seed may need to be exposed to light for germination. Among high-elevation plants that exhibit some form of dormancy, photosensitive seed dormancy is more common than temperature-controlled dormancy (Amen 1966).

At Olympic National Park, we have propagated this species from seed for a number of years successively. Although some suggested that it would take 5 to 10 years for seed propagation, we have grown *Phyllodoce* from seed to a branched, 6-inch (150-millimeter) plant in 3 years. Here are some important generalizations to keep in mind when growing *Phyllodoce* from seeds:

- Seeds probably need light to germinate and should be sown on the soil surface. Never cover seeds with any soil medium.
- The seedlings are minute and grow slowly, needing a full year to reach a sturdy size that will survive transplanting.
- The seeds are even more sensitive to temperature fluctuations, extremes, and low relative humidity than are rooted cuttings. Flats of seedlings must be protected from desiccation and direct sunlight during the summer and transplanted during the winter or spring. Some mortality is to be expected, but mortality can be reduced by storing the flats in a cool shady place.
- Without importation of native soil with their mycorrhizal symbionts, heather seedlings need supplemental phosphorus and trace elements.

Soil Medium for Seed Propagation

Material	Percent of soil medium
High-grade sphagnum peat moss	40 to 50
Fine, aged Douglas-fir bark	30 to 40
Propagation-grade perlite or high-grade, ⅜-inch- (9.5-millimeter-) minus white pumice	10 to 20

Selection of Cuttings

Cuttings from lateral shoots of *Phyllodoce* growing in shaded understory will root easily, and should be taken in the semiripened region between the distal softwood candle and the proximal mature secondary (hardwood) growth. Cuttings that are too soft will deteriorate quickly. Hardwood cuttings require special treatment for rooting. The ideal semiripe cutting is between 3 and 5 inches (about 80 to 130 millimeters) long. The cutting should be long enough so that the semiripened portion of the stem can be inserted in a flat of propagation soil.

Avoid taking actively flowering or fruiting shoots, or shoots with newly set buds. Latent buds appear as small protuberances along the terminus of the softwood shoot. Tall specimens of *Phyllodoce empetriformis*, revealing the flush of etiolated, vegetative growth, which is valuable for stem propagation, occur abundantly in shaded areas under the canopy of *Abies lasiocarpa, Chamaecyparis nootkatensis*, and *Tsuga mertensiana* in high montane and subalpine plant communities. Heavily shaded ravines and streambanks with northwest and northeast aspects are good collection sites. In general, plants growing in full sun will be stunted and woody, and are less valuable for obtaining propagules. Shoots that develop in full sun also will have a shorter zone of semiripe wood.

Preservation of Cuttings

Keep fresh cuttings cool, moist, and aerated. Mature leaves of *Phyllodoce empetriformis* are frost resistant, but the new growth required for semihardwood propagation will burn (turn brown) if the temperature drops much below freezing.

1. Heavy 1-gallon (3.8-liter), zip-seal bags can be used for collecting cuttings in the backcountry. Fill each bag about half full. Thoroughly moisten the cuttings before sealing the bags for transport.
2. Store cuttings in the shade and put them under cover at night if the temperature will approach freezing. In the field, bags of cuttings can be stored by filling them with water and weighing them down with rocks in pools or along lakeshores.
3. When carrying cuttings from backcountry areas, leave an air cushion in the zip-seal bag to help keep the cuttings from being damaged. Carry the cuttings in a daypack strapped to the outside of your overnight gear. Bear-resistant food canisters work well for transporting cuttings.
4. Heather stem cuttings can be preserved for several weeks or longer with little loss of viability if they are handled properly at the greenhouse. Rinse the cuttings with fresh water and arrange them in bags so that air can circulate around them. Seal zip-seal bags to prevent cuttings from being desiccated in frost-free refrigeration systems. Cuttings deteriorate rapidly under anaerobic conditions, so they should never be stored in completely air-tight containers.
5. Store the bags in a refrigerator at 33 to 42 degrees Fahrenheit (0.6 to 5.6 degrees Celsius).
6. Rinse the cuttings regularly—every few days if possible—and inspect them for deterioration or desiccation. When cuttings are preserved for several months in this manner, they may begin to form roots in the bags. Cuttings should be treated and propagated as soon as possible after collection.

Treatment: Dilute Solution Presoaking

1. If the *Phyllodoce empetriformis* cuttings have been refrigerated for longer than a week or two, recut them, slicing a few hundredths of an inch (a few millimeters) from the proximal end (the end that was cut straight) with a razor blade or sharp pruner to remove any callus that may have formed and to open the vascular tissue. This will help rooting hormone be drawn into the stem.
2. Remove leaves within half of an inch of the basal end of each cutting.
3. Keep the cuttings in a bucket of cold water during preparation.
4. Mix the dilute soaking solution at a ratio of 1 tablespoon (15 milliliters) Dip n' Grow to 1 quart (0.95 liter) of water in a 1-gallon (3.8-liter) plastic bucket.
5. Make bundles of cuttings using 10-inch (250-millimeter) twist-ties and suspend the bundles in the solution to the depth required. We put 50 to 60 cuttings in a bundle, the number of cuttings that will be planted in a 10- by 20-inch (254- by 508-millimeter) flat. A quicker method is to place a standard 10- by 20-inch (254- by 508-millimeter) flat underneath an inverted plastic hemidome cover, which holds the solution. Insert the cuttings through the slots in the flat. You may use any other method that allows the proximal ends of cuttings to soak, but prevents the distal parts from contacting the solution.
6. Soak the cuttings for at least 24 hours.

Propagation Medium for Cuttings

Adequate drainage is the primary concern with soil media when propagating stem cuttings under intermittent mist systems. Cuttings media should contain enough fine sphagnum peat to lower the pH and give structure to the finely branched roots of *Phyllodoce, Cassiope*, and other ericaceous seedlings. Use equal parts fine sphagnum peat, fine aged bark and perlite for cuttings of these species under mist propagation. If sand is used for propagation, sharp quartz (blasting) sand is best, because it stimulates rooting and is less likely to compact. Small amounts of pumice may be substituted for perlite or sharp sand. One proven formula is described below.

Cuttings Medium for Mist Propagation

- One part fine sphagnum peat
- One part fine, aged Douglas-fir bark
- Two parts horticultural perlite (3⁄8-inch- [9.5-millimeter-] minus pumice or coarse, sharp sand)

Phyllodoce empetriformis, Cassiope mertensiana, and most ericaceous species root well in this mix and can be maintained for as long as 6 months before transplanting. *Phyllodoce* cuttings require longer than 3 months under mist propagation to develop root systems large enough to survive being transplanted into containers. The fine root structure in this species does very poorly in a saturated substrate. Most ericaceous species require soils that are moist but well drained, with high organic content and low pH.

Fifty to 60 cuttings fill a 10- by 20-inch (254- by 508-millimeter) flat efficiently, while allowing enough room for root development. Using a fixed number of cuttings allows the yield ratio to be calculated easily for the flat when the cuttings are potted.

Greenhouse Environment

The propagation environment should be designed to prevent high heat and low relative humidity, increasing the survivability of cuttings during rooting. Intermittent mist systems greatly increase the likelihood of rooting. Use a propagation bench with heating cables or hot water pipes to maintain an optimum bottom temperature of 65 degrees Fahrenheit (18 degrees Celsius).

Transplanting and Hardening Off

Stem cuttings of *Phyllodoce empetriformis* take 3 to 4 months to root. Cuttings are ready for transplanting when their root systems occupy most of the soil in a 10-by-20 flat and are poking out the bottom. Seedlings can be transplanted during the fall when cool weather arrives.

1. Seedlings grown under greenhouse conditions will need to be exposed to sunlight slowly and intermittently in a shaded area outdoors to prevent ultraviolet burn (that would cause the seedlings to turn brown).
2. Use pots that are 2 1⁄4 inches (57 millimeters) square by 2 1⁄2 inches (64 millimeters) deep for cuttings and seedlings. The root systems of some plants may require 3 1⁄2-inch (89-millimeter) deep pots.
3. The potting soil described at the end of this protocol works well for native heathers and other ericaceous shrubs.
4. The roots of heathers are sensitive to desiccation and disturbance. Transplanting is most successful when the air is cool and damp. Take care to minimize root handling. Use a table fork to lift the plants from the rooted or seeded flats. When transplanting from seeded flats, never attempt to transplant individual seedlings; always transplant small clumps of seedlings into pots.
5. Place the soil loosely around the root ball in the pot, and gently tap the bottom of the pot to settle the soil.
6. Water the plants immediately after transplanting with a solution of 9–45–15 water-soluble plant-starter fertilizer diluted to half strength. Maxicrop liquid seaweed can be added to the solution to provide trace elements.
7. Keep transplanted heathers in complete shade for several weeks. These species seem to tolerate moist soil conditions better than dry conditions, but plants that are overwatered or constantly inundated with rain do not fare well.
8. When warm weather arrives, spread wood shavings or bark over the potted heathers to keep the soil shaded and cool.
9. Apply a light watering in the morning to wet the mulch without inundating the soil; evaporation throughout the day will humidify the plants.

Continue a fertilizing regimen of 9–45–15 plant starter diluted to half the recommended strength and applied every 2 weeks. This mix should be supplemented with Maxicrop liquid kelp (at about one-quarter the recommended strength) to provide trace elements that are lacking in commercial soluble fertilizers. As in the formula given below, high-phosphorus bonemeal (3–15–0) should be added to the potting mix to bolster soil phosphate levels. As the growing season progresses, fertilize every 2 weeks with a water-soluble formula of:

Material	Percent in formula
Alaska Fish Fertilizer 5–1–1	60
20–20–20 water-soluble fertilizer	30
Maxicrop Liquid Seaweed	10

Potting Soil for Ericaceous Shrubs

1 cubic foot (0.03 cubic meter) of high-grade sphagnum peat moss

7 cubic feet (0.2 cubic meter) of fine, aged Douglas-fir bark

1 to 2 cubic feet (0.03 to 0.06 cubic meter) of high-grade, ⅜-inch- (9.5-millimeter-) minus white pumice

1 cup (0.24 liter) steamed bonemeal

or

Material	Percent of potting soil
Fine, aged Douglas-fir bark	70 to 80
High-grade, sphagnum peat moss	10 to 15
High-grade, ⅜-inch- (9.5-millimeter-) minus white pumice	10 to 15
Bonemeal	<1

Additional Considerations for *Cassiope mertensiana*

White mountain-heather occupies slopes with northerly and westerly aspects. Luxuriant specimens can be found in damp, shadowy ravines where it may be mixed with *Luetkea pectinata*. It layers readily in the field. Semiripe heel cuttings (where a little older wood is left at the base of the cutting) taken from nonflowering branches root strongly when hormone treatment is used.

The procedure for propagating *Cassiope mertensiana* (figure C–3) is similar to that for *Phyllodoce empetriformis*, using the same soaking solution, soil medium, potting treatment, and fertilizing regimen. Take 4- to 6-inch (100- to 150-millimeter) sprigs of *Cassiope* with several branches in the field and subdivide them at the greenhouse. Trim material that is excessively woody and clean just enough of the lower leaves or branches to immerse cuttings in the soaking bath and insert them in the cutting medium. Roots form abundantly along the lower branches at the leaf axils. If humidity is high, the cuttings may form aerial roots above the soil surface.

Figure C–3—White heather (*Cassiope mertensiana*). Drawings courtesy of the University of Washington Press (Hitchcock and Cronquist 1976).

Wilderness Impacts of Propagation With Cuttings

Cuttings taken from wilderness areas for front-country greenhouse propagation programs can have a significant impact. The goal should be to maximize greenhouse yield while minimizing impacts in the wilderness, such as trampling off trail and excessive pruning of localized populations of a given species. Surveys for good sources of cuttings near the revegetation area should be done early in the season, after snow release. Try to locate as many collection areas as possible to spread the impact of pruning and to increase the genetic variability of the selected stock plants.

Emulating Field Conditions

Our primary recommendation on cultural treatments for increasing rooting, seedling establishment, and survival of difficult-to-grow ericaceous species is to try to reproduce the soil properties and climatic conditions that are observed in the field. This does not require mining wilderness sites for mycorrhizal fungi or replicating the exact nutrient content of native soils. Modest increases of native heathers, *Vacciniums*, and other ericads can be gained by paying attention to soil organic content, soil acidity, soil drainage, greenhouse environment, and plant nutrition. Use mist propagation systems, shade structures, bark soil amendments, and mulches. All of the local resources for soil ingredients should be investigated with the goal of replicating the conditions of native soil.

Figure C–4—Cascade huckleberry (*Vaccinium deliciosum*). Drawings courtesy of the University of Washington Press (Hitchcock and Cronquist 1976).

Huckleberry (*Vaccinium* spp.)

Vaccinium (figure C–4) *deliciosum* berries can be kept refrigerated in zip-seal bags or preserved in the freezer for extended periods until they are ready for processing.

Berry Forage and Processing

1. Process berries in a blender, using a 1:1 ratio of berries to water, until the berries are thoroughly macerated. Nongerminative seeds and pulp will float or sink slowly, so pour off some solution after a minute of settling to obtain a clean batch of seeds.
2. Spread the mixture of seeds, skins, and pulp, with some additional water, in a thin layer on ramey cloth fixed over a screen. Ramey cloth, also called raw cover, is a thin, white fabric often used to moderate temperatures and keep insects off plantings. Leave the cloth in the rain for 1 or 2 days to clean seed and rinse away saccharides and pectic substances or spray the cloth lightly with water from a garden hose. Do not allow the cloth to bake in the sun, because the seeds may stick to the ramey.
3. When the cloth has air-dried for a few hours, the seeds and remaining dry pulp can be scraped into paper bags and kept in a drying room for several weeks.
4. The dried seeds and excess material can be sifted through a screen to collect batches of pure seed.

Pretreatment

Vacciniums vary in their pretreatment requirements: *Vaccinium deliciosum* seed may not require cold stratification, while the seed of *Vaccinium membranaceum* and *Vaccinium ovalifolium* germinate inconsistently and very slowly without stratification. Chill the seeds in sealed plastic bags in the refrigerator for 1 to 3 months. Many *Vaccinium* species require stratification to break temperature-related dormancy.

The edaphic and other environmental conditions favoring the cultivation of *Vacciniums* are similar to those for *Phyllodoce empetriformis* and *Cassiope mertensiana*. Native *Vacciniums* exhibit a type of heterophylly, having evergreen leaves in the first season and deciduous leaves after the second season. *Vacciniums* prefer extremely acidic soil (pH 4.2 to 5.0).

For propagation of *Vaccinium* species, follow the same procedures described for *Phyllodoce empetriformis*. However, because *Vaccinium* seeds are much larger, sow them at a rate of 1⁄4 to 3⁄8 teaspoon (1.2 to 1.9 milliliters) in an 11- by 22-inch (280- by 560-millimeter) flat. As with heathers, never attempt to transplant individual seedlings; always transplant small clumps of seedlings into pots. Transplant the seedlings during cool weather and keep the new transplants in a shaded area for several weeks. The seedlings will still be small (1.6 to 2.4 inches, 40 to 60 millimeters) at the end of the first season and should be transferred from shade to sun over a period of 6 months.

Growing Partridgefoot (*Luetkea pectinata*) and Spiraea (*Spiraea splendens*) in the Olympic Mountains

Collect seed heads of these species when the follicles of dry fruit are beginning to open and the floral structure turns red-brown. Detach floral stems (racemes) down to the basal tuft with florist shears and store them in paper bags for one to several weeks at about 20-percent humidity or lower. Sift seeds through a No. 12 screen and store them in a zip-seal bag inside another zip-seal bag in the freezer.

Stratification Requirements and Seed Treatments

Because there appears to be no temperature-related dormancy in this species, cold stratification is unnecessary. We have seen prolific germination in both of these species without stratification. The seeds may need light to germinate and should be sown on the surface of the medium.

1. *Luetkea pectinata* (figure C–5) seed is sown during February and March on the surface of the seed germination mix. See the soil medium for ericad seed propagation. Follow this protocol for *Spiraea splendens* (figure C–6).
2. Press the seeds by hand or with a flat piece of plastic on the surface of the germination mix in 10- by 20-inch (254- by 508-millimeter) propagation flats at a rate of 3⁄8 teaspoon (1.9 milliliters) of seed per flat. As with the seed of high-elevation ericaceous shrubs, sow *Luetkea* seed on the soil surface.
3. Mist the flats generously and place them on heating mats outfitted with hemidomes or place them under intermittent mist with heating mats. Keep the soil moist until germination.
4. Maintain the soil temperature at 70 degrees Fahrenheit (21 degrees Celsius).
5. Germination will occur in 7 to 10 days (same as for *Spiraea splendens*).
6. When all the seeds have germinated, take the flats off the heating mats and remove the hemidomes during the day. Transition the flats of seedlings to ambient greenhouse temperature and relative humidity.

Figure C–5—Partridgefoot (*Leutkea pectinata*). Drawing courtesy of the University of Washington Press (Hitchcock and Cronquist 1976).

Figure C–6—Spiraea (*Spiraea splendens*). Photo courtesy of J.S. Peterson@USDA-NRCS PLANTS Database.

7. Apply a foliar fertilizer once every 2 weeks after the seedlings have developed true leaves, using a solution of 9–45–15 plant starter that has been diluted to one-fourth strength. Apply the fertilizer with a hand-pump applicator or pressure-tank sprayer as a fine mist until the seedlings are hardy and can support themselves. If the fertilizer is applied at high concentration or too early, the seedlings may burn (turn crispy brown), or excessive moss scum may proliferate in the flats. High nitrogen levels foster fungal pathogens, so never add nutrients to the soil media. Never fertilize seedlings while cotyledons are present. Wait until mature foliage has developed. Fertilize sparingly during the first 3 months of development.

Losses

Most losses of *Leutkea pectinata* occur after the onset of warm weather, when aphid infestations increase rapidly on seedlings stressed from transplanting. Aphid infestations also can occur rapidly. Green aphid species, common on *Luetkea* and *Spiraea*, sometimes can be detected only by using a hand lens. Aphids are commonly found on the underside of new foliage. Patches of wilting foliage and leaf curl are common symptoms of aphid infestation.

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Protocol developed by:
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(Revised April 30, 2004)

Appendix D—Case Studies

Lake Valhalla Project Plan

Henry M. Jackson Wilderness, Wenatchee National Forest, WA.

Description of the Area

Lake Valhalla is in the Henry M. Jackson Wilderness along the Pacific Crest Trail, about 5 miles (8 kilometers) north of the trailhead at Stevens Pass on U.S. Highway 2 in Washington. At 4,828 feet (1,472 meters), Lake Valhalla (figure D–1) is an easy 3-mile (4.8-kilometer) hike.

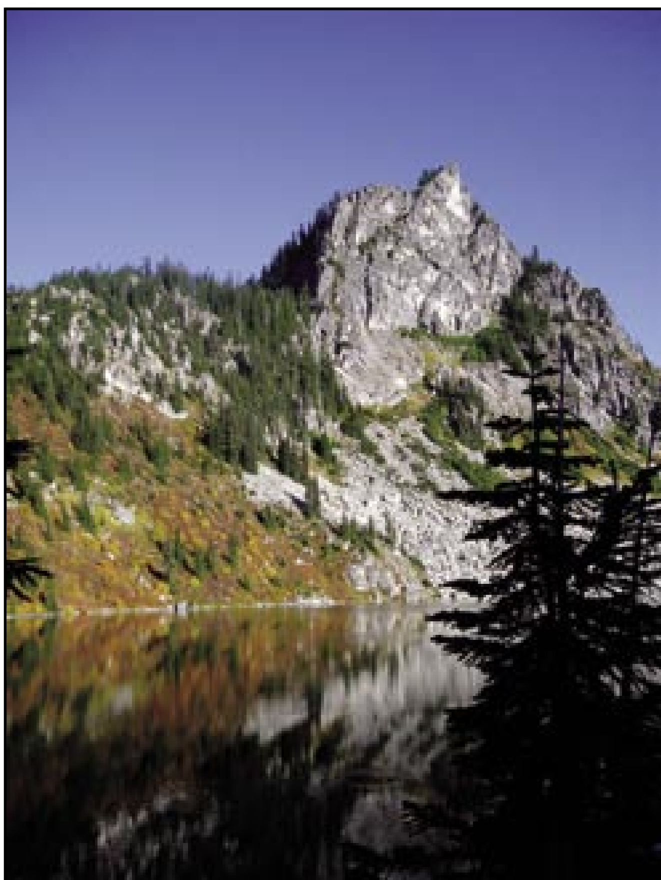

Figure D–1—Lake Valhalla in the Henry M. Jackson Wilderness, WA, has three major factors that place it at risk from damage by visitors. The lake is only a 3-mile hike from the trailhead; it is very picturesque; and it is situated in a fragile heath community.

The lake basin holds some 25 campsites, ranging from just a few square feet (about 0.3 square meter) of trampled vegetation to sites covering more than 3,000 square feet (279 square meters) that are devoid of vegetation. Use could be characterized as moderate to heavy. The lake is one of the Wenatchee River Ranger District's most popular day hiker and backpacker destinations. During the 1990 field season, wilderness rangers encountered an average of 11 groups at the lake during weekends. During the 1991 field season, rangers encountered an average of 12 groups per day on weekends and 4 groups each weekday. Peak use may be considerably higher. On October 5, 1991, a Saturday, a wilderness ranger encountered 27 groups (97 individuals and 3 stock animals) on round-trip day hikes to the lake using the Smithbrook Trail.

Stock use is fairly light, consisting mostly of a few parties of day riders each week who access the lake primarily from the Stevens Pass Trailhead of the Pacific Crest Trail. Some stock users camp overnight at the lake, but most take day trips. The small meadow at the lake is not suitable for grazing stock.

Key resource degradation problems at Lake Valhalla center around six issues:

1. Proliferation of social trails and erosion from them.
2. Damage to soils and vegetation at campsites because of trampling. Eleven sites are not in compliance with forest plan standards.
3. Damage to campsite vegetation and trails by pack and saddle stock.
4. Vegetative damage to the small meadow and soil erosion on the banks of the inlet stream because of grazing by pack and saddle stock.
5. Damage to standing trees and depletion of natural levels of woody debris because of firewood gathering.
6. Loss of the area's wilderness character because of lack of solitude, frequent encounters with other groups, and visible site degradation (figure D–2).

Figure D–2—Fragile sites, such as this campsite at Lake Valhalla, are easily degraded.

Analysis of Current Situation

Problems at Lake Valhalla are caused largely by the social trail network that accesses the lake and lake basin campsites. The Pacific Crest Trail actually skirts the lake, but there has never been a designated system trail to access the lakeshore. Campsites at the lake were never constructed nor defined, resulting in sprawling sites linked by a maze of trails. There is no designated stock holding area or designated stock-user campsite. There have been frequent problems with stock being tied close to water or in campsites.

An additional source of problems at Lake Valhalla is the relatively high level of use, coupled with somewhat infrequent patrol by wilderness rangers. The high level of use has resulted in the area being stripped of firewood. Litter and improperly disposed feces also are frequent problems. At the lake, two Wallowa-style (unenclosed) toilets are used frequently enough to require that they be moved twice a year.

Because of this high level of use, it is virtually impossible for visitors to experience the "solitude or unconfined type of primitive recreation" called for by wilderness designation. On weekends, it is seldom possible to be away from the sights and sounds of others. Often, all of the lake's main campsites are occupied.

Proposed Actions

Unless restrictions on the level of use are implemented (which is not being proposed at this time), none of the impacts occurring at Lake Valhalla can be managed effectively. Rehabilitation of campsites is not practical if use patterns remain unchanged. Some significant actions could be taken to improve conditions at the lake, bringing the area closer to meeting forest plan goals and standards.

Our current proposal is for a work project during the 1992 field season, using a high school work group of the Student Conservation Association. The work plan will be written in discrete sections, allowing for incremental implementation, depending on the availability of resources.

1. **Develop system trail day-use-only areas for access to the lakeshore.**

   Objectives: Eliminate the current problem of eroded, braided trails that access the lakeshore. Improve opportunity for visitor solitude by channeling day users away from campsites. Reduce visual impact of degraded trails. Eliminate the current situation in which one or two camping parties can monopolize the best lakeshore viewpoints.

   This action will require the development of a hardened, defined trail tread and the rehabilitation of several sections of badly eroded trail. Campsite VL-02 would be closed and become the junction of the proposed lake access trail and the Pacific Crest Trail. The new trail section would skirt above boggy areas near the inlet creek, pass near site VL-11, then switchback to the lake near site VL-10.

   Sites VL-10 and VL-11 would become designated day-use areas, because these two sites represent the only easily accessible section of lakeshore.

A small, oak bulletin board, and possibly one or two oak directional signs, will be made and posted. The bulletin board would be placed along the Pacific Crest Trail at the junction of the proposed lake access trail and would include a map of the lake area showing campsites and the location of the day-use area.

2. **Designate a stock hitching area and a stock camp.**

   Objectives: Alleviate conflicts between hikers and stock users. Protect soils, vegetation, and water quality at the inlet of Lake Valhalla. Provide appropriate camping and hitching areas for stock.

   Site VL-01 would become a designated stock-hitching area for persons taking day rides to the lake. This area would be signed and the location shown on the bulletin board at the lake. The site can accommodate a permanent highline as well as one or two hitch rails. These facilities should be adequate for current levels of stock use and should protect the nearby meadow and campsites from trampling.

   A good site for overnight stock use is about 1 mile (1.6 kilometers) south of Lake Valhalla along the Pacific Crest Trail. This site has good feed in a nearby resilient meadow. The site would be signed as a stock site and a sign would be placed there advising stock users that overnight camping with stock is prohibited at Lake Valhalla.

3. **Establish defined tread for the Pacific Crest Trail between sites VL-04 and VL-02.**

   Objectives: Allow recovery of trampled vegetation and the braided trail tread near the main inlet creek.

   Establish tread and build a creek crossing where the Pacific Coast Trail crosses the main inlet creek. This project will include construction of a turnpike and/or a rock ford crossing.

4. **Provide heavy maintenance for the Pacific Coast Trail in the vicinity of Lake Valhalla.**

   Objectives: Reconstruct tread, improve drainage of the Pacific Coast Trail, provide fill material, and transplant vegetation for trail rehabilitation at Lake Valhalla.

   Widen the tread, install drain dips and/or waterbars, and clean existing drainage features. Transport any usable fill material or plant material to the worksite to rehabilitate eroded social trials leading to the lake from site VL-03.

5. **Prepare a special order prohibiting overnight stock use.**

   Objectives: Allow implementation of stock-use aspects of this plan.

   An enforcement plan will be drafted and will outline education to make stock users aware of the closure and the alternative site for overnight camping with stock.

6. **Consider future implementation of a campfire closure for the lake basin.**

   Objectives: Analyze the needs for such an action, which are primarily to protect trees from damage and to reduce impacts at campsites.

   Despite an apparently abundant source of wood in the surrounding area, available firewood is scarce near campsites. However, tree damage and availability of firewood needs to be addressed in more detail before we would propose to ban campfires at lake campsites.

Strategy for Implementation

During the 1991 field season, seed was collected from the Lake Valhalla basin for propagation of subalpine spiraea (*Spiraea densiflora*), subalpine fir (*Abies lasiocarpa*), Sitka mountain-ash (*Sorbus sitchensis*), mountain hemlock (*Tsuga* *mertensiana*), and several sedges and herbaceous plants. A portion of this material will be saved for direct seeding, while some is being propagated by the Forest Service's Wind River Nursery.

The projects listed above would require roughly 1,000 to 2,000 hours of work, depending on the extent to which fill material is brought in to backfill eroded trail sections. Collection of seed or cuttings for plant propagation could take much longer, depending on the scope of specific site-related projects.

Possible offsite sources of fill and plant material for transplants are in the Smithbrook area outside of the wilderness. Such material may need to be transported by helicopter, greatly increasing costs.

Our current plan is to accomplish the bulk of this project with a crew from the Student Conservation Association, probably a 7-person high school work crew. Additional project work will be accomplished by the district wilderness and trail crews.

The estimated first-year cost of the project will be $15,000. Followup work would be required to seed sites and transplant vegetation. In addition, we expect that an increased presence of wilderness rangers will be required over the next few years. The district also hopes to recruit volunteers to assist with some of the followup work. In view of the amount of vegetation needed to rehabilitate trails in this area, the district also may pursue partnerships with other interested groups, such as the Washington Native Plant Society.

Written by:
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1991

2004 Update

This project was implemented largely as described in 1992. A Student Conservation Association high school work crew (figures D–3a and 3b) completed the initial trail work, as well as campsite and trail closures. All fill was collected and hauled locally without the use of a helicopter. A fall planting of greenhouse-grown plant stock was successful, but a spring planting failed, probably because of a lack of soil moisture during the summer season. Because of declining budgets and turnover in personnel, ongoing maintenance of signs and stock structures has been a challenge. The campfire prohibition has been put in place. Overall, area conditions are improving because trails and campsites were reconfigured to handle the level of use in a more sustainable fashion.

Figures D–3a and 3b—Teenagers on a Student Conservation Association high school work crew spent many hours installing and backfilling rock (top) and installing log checkdams (bottom) to stabilize erosion at Lake Valhalla.

Grouse and Hemlock Lakes Campsite Restoration Project, Desolation Wilderness, Eldorado National Forest, CA

Description of Project Environment

Grouse and Hemlock Lakes (figures D–4a and 4b) are located in the subalpine zone at 8,200 to 8,400 feet (2,499 to 2,560 meters) in the Crystal Range of the Sierra Nevada Mountains. The dominant tree species include lodgepole pine, mountain hemlock, and western white pine. The dominant understory vegetation is mountain heather, a short flowering plant that grows on the forest floor. Meadow vegetation also is prominent on the east side of Grouse Lake. Both Grouse and Hemlock Lakes are relatively small. The area surrounding these lake basins consists mostly of granitic soils with sparse vegetation and steep terrain.

Figures D–4a and 4b—Ease of access to Grouse and Hemlock Lakes (top) in the Desolation Wilderness, CA, led to extensive impacts (bottom).

Access

Grouse and Hemlock Lakes are about a 3-mile (4.8-kilometer) hike (Hemlock Lake is about ½ mile, 0.8 kilometer, past Grouse Lake) from the Twin Lakes Trailhead, which is in the popular Wrights Lake Recreation Area. Because it is so close to a popular recreation area, the Twin Lakes Trailhead is one of the more heavily used trailheads for the Desolation Wilderness. With Grouse and Hemlock Lakes just a short hike from such a popular trailhead, these lakes receive high overnight and day use.

Visitor Attractions

- Lakes serve as a destination (scenic beauty, fishing opportunity)
- Relatively short hike from an easily accessed trailhead (the trailhead is near a popular campground and summer homes tract; access to the trailhead is by a paved road)

Causes of Impacts and Management of the Wilderness Resource

With Grouse and Hemlock Lakes just a short hike from a popular trailhead, these lake basins receive a great deal of overnight and day use. Because of the terrain, most of this use is concentrated in a small area in the sensitive lake basins. The amount of visitor use has resulted in a proliferation of campsites and social trails around the lakes. Most of this use is during the summer months (June through September), with the peak use during July and August. In most years, this area is covered by snow from November through June.

Management Actions Taken To Reduce Impacts

Grouse and Hemlock Lakes were being impacted by camping at sites within the sensitive lakeshore zone, riparian areas, and meadows. The impacts associated with this use included:

- Loss of native vegetation
- Soil compaction
- Increased erosion
- Reduced water quality because the sediment load increased after vegetative cover was lost and the soil was compacted
- Reduced visual and scenic beauty

The following is a brief description of the management actions taken to reduce impacts. More specific information will be provided later.

- Established designated campsites within 500 feet (152 meters) of Grouse and Hemlock Lakes.
- Restored eliminated campsites and social trails to natural conditions. Restoration activities involved revegetating the area by breaking up compacted soil, mulching with native materials, transplanting native plants found onsite, and placing rocks and logs to give the area a natural appearance and to encourage groups to use the well-established, durable sites and avoid the sensitive areas (figure D–5).
- Installed temporary signs where necessary to keep visitors from walking through and trampling the restoration site. Rocks and logs couldn't do the job everywhere.
- Increased wilderness ranger presence to provide education and inform the public about the project.
- Prepared a forest order for implementation (to be completed in 2004).
- Conducted monitoring (observations by wilderness rangers and photopoint documentation). Subsequent restoration has been completed based on the monitoring information.

Figure D–5—Rocks and logs were installed on social trails and closed campsites to deter use and provide microhabitat for plantings.

Standards, Guidelines, and Direction From the Wilderness Management Plan

The Desolation Wilderness Management Guidelines restrict camping within 500 feet (152 meters) of Grouse and Hemlock Lakes to designated sites. The number of designated sites will be correlated with the quota so campers will not have to be assigned a specific site, but will have the freedom to choose their preferred designated site. Campers can camp without restriction if they are farther than 500 feet (152 meters) from the lakeshore. Allow natural recovery in areas where vegetation that has been impacted can revegetate naturally in less than 10 years. If recovery is expected to take longer than 10 years, develop and implement site-specific restoration plans to include closure to use and/or revegetation using species native to the area.

In addition, the Desolation Wilderness Management Guidelines provide direction to implement a zone quota system, which has been an effective method of dispersing campers and appears to have reduced the number of overnight visitors to Grouse and Hemlock Lakes. The quota for this zone is 12 people, which was implemented in 1999. Before 1999, a trailhead quota system was in place. The quota for the trailhead was 39 people. Because there was no control over where the 39 people ended up, Grouse Lake often was overcrowded. It was the first lake backpackers came to after a steep climb.

Results of Minimum Requirements Analysis

1. Is the action necessary? Yes.
2. What are the minimum tools? Because other techniques failed to return the area to standards, restoration treatments were part of the minimum tool necessary to meet management direction. No motorized equipment was needed.

Prescription for Restoration

The Three Es:

Engineering—You must be able to remove or reduce the impact to the site.

Education—When sites are being impacted by recreational use, you must inform the public to get cooperation.

Enforcement—When engineering and education don't do the job, you must be able to fall back on law enforcement.

Site Protection and Confinement

Campsites were designated within 500 feet (152 meters) of Grouse and Hemlock Lakes. The number of designated campsites was correlated with the quota so that users would not be assigned a specific site, but would have the freedom to choose their preferred designated site. Designated campsites were selected based on campsite durability and proximity to the lakeshore, streams, meadow areas, and other campsites. Four sites were designated at Grouse Lake and three sites were designated at Hemlock Lake. The zone quota for the Hemlock Lake zone (which includes Grouse and Hemlock Lakes) is 12 people.

- Reduced or eliminated use from impacted sites (or restoration sites).
- Encouraged use at selected campsites and areas suitable for visitor use.
- Used rocks and logs for a natural appearance, and to encourage groups to use the well-established, durable sites and discourage use of the sensitive areas. Rocks and logs were partially buried in closed campsites and at the beginning of social trails leading to sensitive areas and old campsites.
- The tools used included: shovel, rock bar, Pulaski, and a come-along.

Soil Treatments

- Broke up compacted soil using a shovel and Pulaski.
- Mulched the bare ground using native materials from the area, including pine needles and meadow grasses.

Vegetative Treatments

- Transplanted mountain heather, lodgepole pine seedlings, and meadow grasses.
- Used a lawn-coring aerator (nonmotorized), grass plugger, and a mulch of meadow grasses when spreading the seed in the meadow areas.
- Most of the transplanting was completed in the late fall, when the plants had gone dormant and precipitation was likely.

Regulations, Signs, and Education

- Temporary signs are in place at selected restoration sites where it was difficult to discourage visitor use through engineering. The signs are on a 4- by 4-inch (about 100- by 100-millimeter) wooden post: "Restoration Site: Please help restore this area by walking and camping elsewhere." (figure D–6).

Figure D–6—Restoration closure signs helped deter use at closed sites.

- Information about the restoration project and a map with the designated campsites is included in a wilderness-regulation handout that is attached to each overnight wilderness permit.
- Increased wilderness ranger presence is being provided at these sites to allow rangers to talk with the public about the project and enforce the camping restrictions.
- A forest order, which would prohibit camping outside of designated campsites within 500 feet (152 meters) of Grouse and Hemlock Lakes, has not been completed, but is planned to be in place in 2004. For the most part, this project has been well received and compliance has been about 90 percent. Most of the success has probably been because of the increased presence of the wilderness rangers and the public contacts they have made.

Work Accomplished

Budget: $8,000 (fee demo)

Workforce: Project leader and five-person crew

Partnerships: None. Because this was our first wilderness restoration project, we decided to accomplish the work with employees instead of volunteers. Now that we have experience with this type of project, volunteers could be used effectively.

Monitoring Results

Monitoring was conducted through wilderness ranger observations, campsite condition inventories, and photo documentation. Although the restoration project was a success, monitoring results indicate some followup work is needed.

Wilderness Ranger Observations

There has been about 90-percent compliance for the designated campsite restrictions within 500 feet (152 meters) of Grouse and Hemlock Lakes. The temporary signs at selected restoration sites have reduced the amount of use (visitors walking through or camping on these sites) to a level that will allow the site to recover within 5 to 10 years. In addition, dissemination of information about the restoration work and the designated campsite restrictions has improved, making users more aware of the problem and leading to better compliance with the restrictions.

Campsite Condition Inventories and Photo Documentation

Campsite inventories were conducted at Grouse and Hemlock Lakes in 1992. Twenty-two campsites were documented at Grouse Lake and eight campsites were documented at Hemlock Lake. By 2001, just 16 campsites were documented at Grouse Lake. The number of documented campsites at Hemlock Lake had not changed. After the project, the number of campsites at Grouse Lake was reduced to eight (four designated sites within 500 feet (152 meters) of Grouse Lake and four campsites outside the 500-foot (152-meter) zone). At Hemlock Lake, the eight campsites were reduced to five (three designated sites within 500 feet (152 meters) of Hemlock Lake and two campsites outside the 500-foot (152-meter) zone). Photopoints were established for each campsite.

Followup Actions and Lessons Learned

Additional restoration has been completed since the initial work in 2001. Most of the additional work was transplanting, with some minor rock and log moving to provide a more natural appearance at the restoration sites that were still being used.

Tips and Lessons Learned

- No instant gratification—Restoration projects take years to complete and even longer before the improvements become apparent.
- Recognize long-term implications—Monitor progress and plan for additional work. You can't just do the initial work and then leave an area to recover on its own.
- Don't take on too much—Concentrate your efforts in a few small sites or on a portion of a larger site.
- Transplanting can be difficult—Don't spend a lot of time on transplanting until you know your plants will survive and become established.
- Monitoring is important—At a minimum, establish photopoints and record locations of the restoration sites using a global positioning system receiver.

Report submitted by:

Jennifer Ebert, wilderness resource manager
Eldorado National Forest

Mill Flat Restoration Pine Valley Mountain Wilderness, Dixie National Forest, UT

Description of the Area

Mill Flat is a subalpine meadow in the Pine Valley Mountain Wilderness on the Pine Valley Ranger District of the Dixie National Forest in southern Utah. Mill Flat is about a 20-acre (8.1-hectare) grassy meadow at 8,500 feet (2,591 meters). The surrounding vegetation is mixed conifer and high-elevation shrubs, such as mountain mahogany, service-berry, and juniper. The mixed-conifer forest includes Engelmann spruce, white fir, Douglas-fir, ponderosa pine, and aspen. The meadow includes the upper reaches of Mill Creek and an unnamed, seepy, grassy, riparian area.

Causes of Impacts and Management of the Wilderness Resource

Mill Flat (figure D–7) is a pleasant mountain meadow that has always provided livestock respite from the summer heat at lower elevations. Recreational livestock and permitted

Figure D–7—Mill Flats had substantial changes in vegetative composition because of overgrazing. Restoration involved improving management of grazing. No active revegetation was needed.

cattle have overgrazed the area, leaving stunted and severely damaged forage plants and forbs. Much of the area is denuded of plants, which has led to gullying and erosion in the riparian areas. Cows like to wallow and root with their heads in the soft earth of the gully banks, enlarging the gullies.

When I first became aware of the conditions at Mill Flat, I asked the question, "Why doesn't grass grow in Mill Flat?" Often, the answer was, "Grass won't grow in Mill Flat, never has, never will." I determined to discover if this was true.

Figure D–8—Commercial livestock were rotated between three pastures separated by electric fences.

Prescription for Restoration

I enlisted the help of various specialists, such as soil scientists, hydrologists, vegetation specialists, and wildlife biologists, searching for a reason why grass wouldn't grow in Mill Flat. Their answers were the same, "Grass can grow in Mill Flat, there must be a mechanical reason why it's not growing. Maybe horses and cows." We obtained a special order to restrict grazing by recreational livestock and enlisted the help and cooperation of the grazing permittees to limit grazing by permitted cattle. Because we couldn't afford to station a herder or wilderness ranger at the meadow to monitor the meadow full time, we decided to use a three-wire electric fence to control grazing (figure D–8). This decision came as the result of an informal minimum-tool evaluation.

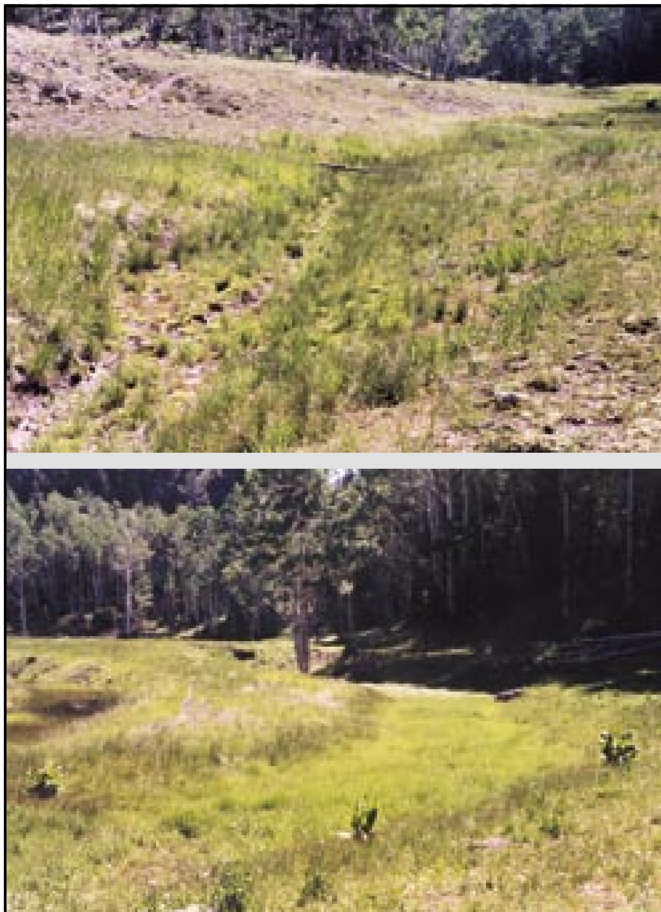
We have experienced fairly good success with the electric fence, although at first we did have some vandalism and some visitors let the fence down so their stock could graze inside. It took some time to change the attitude of some visitors and ranchers so they could accept the fence and the idea that the fence was going to stay. I think persistence and patience on our part have been the reasons for their change of attitude. We also have tried to explain the project's goals to visitors. In the past few years, folks have begun to accept and support the project.

Monitoring Results

After 9 years of protection by the electric fence, vegetation is healing and rehabilitating itself (figures D–9a and 9b) in the meadow area. The gully banks have filled in with grasses and forbs, the uplands are now showing a great deal of cover, and the tiny grasses are starting to grow to a more natural height. There has been significant recovery throughout the meadow, including the filling in of the 100-year-old trail that has run through the middle of it. This trail has been rerouted to the edge of the meadow. There has been a significant recovery of quaking aspen. Many new shoots and saplings now grow within the fenced area. We have not done any other restoration, such as scarifying or reseeding.

We have a very good working partnership with the local chapter of the Back Country Horsemen of America. They help us put up and take down the fence, help monitor the fence, and maintain it during the summer. Because of reductions in wilderness and trail budgets, we rely heavily on these volunteers.

In conclusion, I would say that we have been successful with this project. The visitors and the cattlemen are cooperating with the closure. After 9 years of protecting this meadow, I can say without qualification: "Grass will grow in Mill Flat."



Figures D–9a and 9b—These before (top) and after (bottom) photos show the response of vegetation after grazing pressure was reduced at Mill Flats.

If I can be of any further help or assistance, or can supply any other information, please feel free to contact me. I can be reached at 435–652–3124.

Fredric R. Ybright, wilderness coordinator
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Pine Valley Ranger District
Dixie National Forest
196 East Tabernacle St.
St. George, UT 84770

Edith Lake Campsite Restoration Project, Sawtooth Wilderness, Sawtooth National Recreation Area, ID

Description of Project Environment

Edith Lake (figure D–10) was formed by glaciation. The lake sits in a small cirque basin formed in the Idaho batholith at about 8,660 feet (2,640 meters) in the subalpine zone of the Sawtooth Mountains of south-central Idaho. The dominant tree species include lodgepole pine and subalpine fir. Grouse whortleberry is dominant in the understory. Slopes are steep, vegetation is sparse, and soils in this area are predominantly shallow, silty pockets along shorelines or among granitic outcrops. Temperatures are extreme, the growing season is short, and moisture comes predominantly in the form of snow.

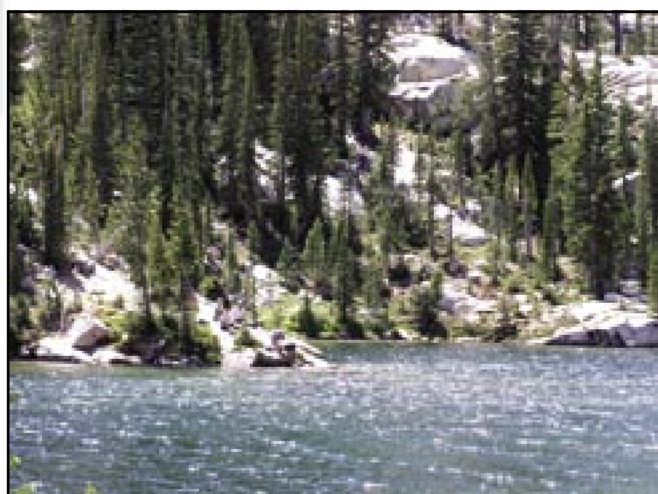

Figure D–10—Edith Lake in the Sawtooth Wilderness, WA.

Access

Edith Lake is accessed by traveling 6 to 12 miles (about 10 to 20 kilometers) from any one of three trailheads on the east side of the Sawtooth Wilderness. Of the four most used wilderness trailheads, two provide direct access to Edith Lake. Several other popular lakes can be accessed by the Edith Lake Trail. Visitors can incorporate a loop into their trip by using this trail. Campsites at Edith Lake have been popular since the 1930s, receiving both overnight and day use.

Visitor Attractions

- Destination area for scenic beauty and fishing
- Edith Lake Trail provides access to other highly popular lakes, as well as an option for a loop hike
- Relatively short hike from an easily accessed trailhead (the trailhead is near a popular campground and a summer-home tract)

Causes of Impacts and Management of the Wilderness Resource

Edith Lake has been a popular Sawtooth Mountain destination since the early 1900s. Snow often does not leave campsites until July. Users arrive before the campsites have dried out, while the soil is still wet and easily compacted. Visitors' activity has reduced the possibility for spring revegetation and increased compaction and the potential for sheet erosion. Because access is easy, both day and overnight use are fairly high. The peak use occurs during July and August, coinciding with the very short growing season.

Management Actions Taken To Reduce Impacts

Soils in most of the overused campsites are compacted. The surface layer has a platy structure, with surface compaction ranging from 6 to 12 inches (about 150 to 300 millimeters) deep. Before the compacted areas can revegetate, the surface soil must be broken up or loosened so seeds can penetrate the soil.

Edith Lake was being heavily impacted by camping in sites that straddled the trail or that were within the sensitive lakeshore zone. The impacts associated with this use included:

- Loss of native vegetation
- Soil compaction
- Increased erosion
- Reduced water quality because of increased sediment load after vegetation was lost and the soil was compacted
- Reduced visual and scenic attractiveness

The following is a brief description of the management actions taken to reduce impacts. More specific information is provided later.

- Implemented closure to overnight stock use within 200 yards (183 meters) of the lake in 1998.
- Five sites were rehabilitated after the high-use season in 2002 and left in a condition that made overnight use undesirable, if not impossible. Three of the closed sites either overlapped the system trail or were right beside it. A fourth was on the eastern lakeshore. Compacted soil was broken up and reseeded with locally gathered seeds in the hopes that vegetation could become established once again. (Note: Because the seeds were gathered late in the season, many seeds already had dropped.) Logs were strewn across the sites and large rocks were buried to prevent material from being moved easily by wilderness visitors. Some members of the crew were rehabilitation artists, making the altered sites appear as natural as possible.
- An alternate site (figure D–11), suitable for large groups, was found and a user trail was

created so visitors could find it. A small area of one of the reclaimed sites was left unaltered to allow a highline to be placed where day riders could tie their stock. An access to the lake was left through another reclaimed site.

Figure D–11—This campsite was opened after five others in less suitable areas were closed and rehabilitated.

- During the summer of 2003, the changes were explained to front desk personnel so they could help visitors locate the preferred group site and understand how they could help the rehabilitation. "Closed to Camping" signs were placed at this site. Another small sign was placed at the junction of the maintained trail and the trail that directed users to the new site for large groups.
- During the late summer of 2003, more local seed was gathered (figure D–12). Our timing was better this year and seeds had not dispersed. The seeds were mixed with mud and manure from the site and formed into small balls that were scattered at the sites.

Figure D–12—Gathering seed used to restore vegetation at closed campsites.

- During 2004, plant growth was inventoried. Tree seedlings and new plugs of grass and whortleberry were transplanted onsite.
- Monitoring information (observations by wilderness rangers and photopoint documentation) was collected. Subsequent restoration was completed based on this documentation.

Standards, Guidelines, and Direction From the Wilderness Management Plan

Direction in the Sawtooth Wilderness Management Plan (Forest Land and Resource Management Plan Amendment 1997) provides:

- Overall Goals
  - Natural biological processes are not changed over time by human use.
  - The visitor is provided opportunities where naturalness, solitude, and freedom are paramount.

- The minimum-tool concept will be used to accomplish site-specific work that least degrades wilderness values.
- Stock users and large groups are encouraged to camp in sites that can withstand their use.

Guidelines for Site Selection

Existing sites should be used whenever possible. The following guidelines are to be used for establishing new sites or for rehabilitating existing sites.

Designated Group Campsites

- Farther than 100 feet (31 meters) from water, or for existing sites, 50 to 100 feet (15 to 31 meters) from water—with a vegetative buffer
- Farther than 100 feet (31 meters) from trails, or for existing sites, 50 to 100 feet (15 to 31 meters) from trails—with a visual buffer
- Larger than 1,000 square feet (93 square meters)
- Impact levels 3 to 5
- 0- to 5-degree slope

Stock-Holding Facilities

- Rocky terrain with little vegetation
- Less than 2-degree slope within 100 feet (31 meters) of water
- Less than 5-degree slope if 150 to 300 feet (46 to 91 meters) from water
- Less than 10-degree slope farther than 300 feet (91 meters) from water
- Not in draws or where water may concentrate

Toilets

- Farther than 300 feet (91 meters) from water
- Farther than 100 feet (31 meters) from campsites
- Farther than 100 feet (31 meters) from trails
- Not visible from lakeshore or trails
- Not in draws or areas where water may concentrate

Desired Future Condition

Edith Lake is in a Class III opportunity class with the following desired future condition:

Clear evidence of camping. Minimal number of sites generally limited to areas previously disturbed. No further degradation of existing campsites. Expect some loss of ground cover. Evidence of stock confined to stock holding areas. Area of disturbance will have some evidence of soil compaction. Little evidence of wood gathering and some evidence of campfires.

Results of Minimum Requirements Analysis

1. Is the action necessary? Yes.
2. What are the minimum tools? Because other techniques failed to return the area to standards, restoration treatments were part of the minimum tool necessary to meet management direction. Motorized equipment was not considered.

Prescription for Restoration

A holistic restoration prescription was developed to improve conditions for reestablishing vegetation and for redirecting recreational use at the site.

Site Protection and Confinement

Before any restoration, an effort was made to analyze where users would go and the resulting impacts if sites were closed. We identified the sites that would remain open, the sites that should be restored, and a new site where we could direct visitors.

The sites that were selected for restoration were made as unusable as possible. Logs were strewn throughout the site, rocks were iceberged (the larger portion was buried), and native debris (pine needles, fine gravel) was strewn across the site to mimic the appearance of the surrounding area. Logs and rocks were placed on the site to restrict use and provide shade for vegetation.

Soil Treatments

The soil in this area was badly compacted, so we tried to break it up to allow root establishment. We used Pulaskis, shovels, rock bars, and picks, but despite all our effort, we were unable to break up the soil deeper than 6 inches (150 millimeters). Manure was collected onsite and dispersed with the locally gathered seeds.

Vegetative Treatments

Initially, lodgepole and subalpine-fir seedlings were the only transplants. We chose to transplant these seedlings during early fall and watered them heavily during planting. Afterward, we transplanted mountain heather, elk sedge, grouse whortleberry, and saplings (lodgepole, whitebark pine, and subalpine fir).

Supporting Regulations, Signs, and Education

- Special order "Prohibiting camping with equine stock" is in place.
- Carsonite signs with a standard no camping symbol and "Protect the wilderness environment" stickers were placed at each site.
- Signs were displayed on information boards at trailheads. These included a small map indicating where campsites were available.

Work Accomplished

Budget: $1,430 (salary)

Workforce: A project leader and seven-person crew for 2 days each for the initial implementation. One wilderness ranger spends 1 day annually monitoring the site and doing additional work.

Partnerships: None. The work was accomplished as an end-of-season project by wilderness rangers.

Monitoring Results

Monitoring was conducted through wilderness ranger observations, campsite condition inventories, and photo documentation. Overall, I would consider the project a success. However, the degree of success varied across sites—two of the sites were only partially restored, leaving a portion of the sites for day use by stock and for access to the lake. These two sites have been the least successful. At one of the sites, no plants have grown, but the iceberg rocks are still in place. Recent observations determined that fires have been built, despite a no-campfire regulation that is in effect. The other site allows access to the lake and, despite signs, it appears that camping is continuing. Some of the debris has been removed and there is little regrowth at the site. The remaining three sites have multiple seedlings, and some sedges and grasses are reestablishing themselves (figures D–13a and 13b). All but one of the transplanted saplings survived and appear to be growing.

Future monitoring needs to include growth rates of vegetation.

Use of the new site has been very low. The only sign is at the small user trail that accesses the site. We surmise that users aren't seeing the sign. We have not identified any proliferation of campsites.

Figures D–13a and 13b—This heavily impacted campsite (top) at Edith Lake has begun to recover (bottom).

Followup Actions and Lessons Learned

Restoration has continued annually since the initial project in 2002. Transplanting and collection and dispersal of local seed has taken place annually and is planned to continue. Some logs had to be moved into the campsites.

Tips and Lessons Learned

- Plan ahead. Understand the implications of closing a site.
- Scarification of soil is critical to establishing new growth.
- Timing is critical. The late season works well for transplants and seed dispersal. Wait too late and you miss the window for collecting seed.
- Monitoring is important to understand success and failure and to plan work. A good inventory as soon as the project is initiated is useful as a baseline.
- Work with your frontliners (receptionists and other employees who contact the public) to ensure that users are informed of your objectives.
- It is better to be successful at a few sites than to be unsuccessful at many sites. Choose your sites carefully.

Report submitted by:

Liese C. Dean, wilderness program coordinator
Sawtooth National Recreation Area

Wilderness Restoration Case Study, Lake of the Woods Campsite Restoration Project, Desolation Wilderness, Pacific Ranger District, Eldorado National Forest

Lake of the Woods (figure D–14) is in the subalpine zone, at about 8,000 feet elevation in the Crystal Range of California's Sierra Nevada Mountains. Lake of the Woods is one of the larger lakes within the Desolation Wilderness. The lake basin is densely forested with lodgepole pine, mountain hemlock, and red fir. The area surrounding this lake basin consists mostly of granitic soils with sparse vegetation and steep terrain.

Figure D–14—Lake of the Woods in the Desolation Wilderness, CA.

Access

Lake of the Woods is a 5-mile hike when accessed by the popular Echo Lakes Trailhead. With a 15-minute boat taxi, access to Lake of the Woods is a fairly easy 3-mile hike. The boat taxi is very popular, and contributes to the popularity of Lake of the Woods as a destination in the Desolation Wilderness.

Visitor Attractions

- Destination area for scenic beauty, fishing opportunity.
- Relatively short hike from a trailhead that is accessed easily from a major highway near the Lake Tahoe Basin. In addition, the trailhead is near a popular campground and a summer homes tract.

Visitor Use (Amount/Pattern/Type/Season)

Because Lake of the Woods is an attractive destination just a short hike from a popular trailhead, it receives an excessive amount of overnight and day use. The terrain concentrates most use in a small area inside the sensitive lakeshore zone. Lake of the Woods tends to attract larger groups (maximum group size in the Desolation Wilderness is 12 persons per group) compared to other destinations within the Desolation Wilderness. Most use occurs during the summer months (June through September), with peak use during July and August, coinciding with the very short growing season. In most years, the area near Desolation Lake is covered by snow from November through June.

Management Actions To Reduce Impacts

Lake of the Woods was being heavily impacted by camping in sites that were within the sensitive lakeshore zone. The impacts associated with this use included:

- Loss of native vegetation
- Soil compaction
- Increased erosion
- Reduced water quality because of increased sediment load (caused by the loss of vegetative cover and soil compaction)
- Reduced visual and scenic attractiveness

Management actions to reduce impacts included:

- Campsites in undesirable locations were restored to natural conditions. The campsites that had the highest impacts were the first to be restored. Restoration activities involved breaking up compacted soil, placing rocks and logs to give the area a natural appearance, and mulching the surface with native materials (figures D–15a and 15b).

Figure D–15a—Campsites that had the highest impacts were the first to be restored.

Figure D–15b—Campsites in undesirable locations were restored to natural conditions.

Some vegetation was transplanted—with limited success. Because hazard trees had not yet been eliminated, campsites could not be designated before the restoration work was completed. Some obvious campsites were left open to encourage visitors to camp there instead of at the restoration sites.

- Because the campsite proliferation was so extensive (including several campsites that merged into one large campsite) and rocks and logs to restore the site's natural appearance were in short supply, snags were directionally felled by blasting to provide some ground cover and discourage use (figures D–16a and 16b).

Figure D–16a—Several campsites merged into one large campsite. Rocks and logs to restore the site's natural appearance were in short supply.

Figure D–16b—Snags were directionally felled by blasting to provide some ground cover and discourage use.

- After the blasting project removed the hazard trees, nine campsites were designated.
- Temporary signs were installed where it would have been difficult to use rocks and logs to keep visitors from trampling the restoration site (figures D–17a and 17b).

Figure D–17a—Access trails leading to campsites in undesirable locations also need to be closed.

Figure D–17b—Temporary signs were installed at access trails and campsites to keep visitors from trampling the restoration site.

This was particularly important because the designated campsite restrictions were not in place before the restoration work was completed.

- Wilderness ranger presence was increased to inform the public about the project and its purpose.

Standards, Guidelines, and Direction from the Wilderness Management Plan

Desolation Wilderness Management Guidelines (final environmental impact statement signed in 1998):

- Restrict camping within 500 feet of Lake of the Woods to designated sites. The number of designated sites will be correlated with the quota so that users will not be assigned a specific site, but have the freedom to choose their preferred designated site. Campers can camp unrestricted if they are more than 500 feet from the lakeshore.
- Allow areas where vegetation has been impacted by human use to revegetate naturally if recovery is expected to take less than 10 years. Where recovery is expected to take longer than 10 years, develop and implement site-specific restoration plans to include closure to use and/or revegetation using species native to the area.

Results of Minimum Requirements Analysis

1. Is the action necessary? Yes.
2. What are the minimum tools? Because other techniques failed to return the area to standards, restoration treatments were part of the minimum tool necessary to meet management direction. Some traditional restoration techniques were not adequate for larger campsite

areas, so snags were blasted as a restoration technique (figures D–18a and 18b).

Relying on blasting rather than using crosscut saws to fell snags allowed the natural wilderness character to be maintained. If the trees had been felled with crosscut saws, saw marks would have been left on the trees. Motorized equipment was not considered.

Figure D–18a—This stump appears to have been broken off naturally, helping to maintain the wilderness character.

Figure D–18b—After blasting was complete, the campsite had a natural appearance and the fallen logs discouraged camping on the restored site.

Site Protection and Confinement

Before any restoration work began, managers made an effort to analyze where users would go and the impacts they would cause if sites were unavailable at Lake of the Woods. We identified the campsites that would be designated for continued use and those that should be restored.

- Groups were encouraged to use the well-established, durable sites that were designated for camping.
- Use was reduced or eliminated from impacted sites (or restoration sites).
- Rocks and logs were added and partially buried so they appeared to have been placed naturally and to discourage visitors from trying to move them.

Soil Treatments

Because the soil in this area was severely compacted, pulaskis and shovels were used to break it apart to allow root establishment. The bare ground was mulched with native materials from the area, including pine needles.

Vegetative Treatments

Some native vegetation was transplanted, but success was limited. Breaking up the compacted soil and discouraging visitor use should allow vegetation to recover over the long term.

Regulations, Signs, and Education

- Signs are in place at selected restoration sites where it was difficult to discourage visitor use with rocks and logs. The signs are on a 4- by 4-inch (100- by 100- millimeter) wooden post saying: “Restoration Site: Please help restore this area by walking and camping elsewhere.”

- Information about the restoration project and a map with the designated campsites are included in a wilderness regulations handout that is attached to each overnight wilderness permit.
- The time wilderness rangers spent at these sites was increased so they could talk with the public about the project and enforce the camping restrictions.
- A Forest Order was implemented that prohibits camping outside of designated campsites within 500 feet of Lake of the Woods.

For the most part, this project has been well received and compliance has been about 90 percent. Most of the success is probably due to the increased time wilderness rangers have spent in the area and the contacts they have made with the public.

Work Accomplished

Budget: $23,000 (2-year project), of which $8,000 was for blasting. The cost includes project planning, environmental analysis, and implementation (partially funded by a grant).

Workforce: Initial restoration work, 2004—project leader and five-person crew for 2 weeks; blasting, 2004—2 certified blasters, 2 packers, 11 mules, 6 other crewmembers for 3 days, 15 cases (800 pounds) of explosives; restoration work, 2005—project leader and 11 volunteers for 4 days.

Partnerships: Worked with Wilderness Volunteers (*http://www.wildernessvolunteers.org*), a nonprofit organization, during 2005.

Monitoring Results

Monitoring was conducted through wilderness ranger observations and photo documentation.

August 2004: Initial restoration work was completed. About 12 campsites/areas were restored, two of which were larger areas. The restoration work was completed before hazard trees could be removed from some campsites, so those campsites could not be designated. Some campsites in less sensitive areas were left open to encourage visitors to use those sites, rather than the restored campsites. For the most part, this approach was successful. However, visitors moved a few rocks and logs so they could use some of the restored campsites.

October 2004: A blasting project was undertaken to remove hazard trees from designated campsites and to provide fallen logs in areas where logs and other material needed to restore campsites were in short supply. Nine campsites were designated at this time.

June 2005: After one winter, we were extremely pleased with the results. The fallen logs were especially effective at closing sensitive areas and discouraging use.

August 2005: More restoration work was completed with the Wilderness Volunteers nonprofit organization. The restoration work focused on several of the campsites that had been missed during the initial restoration work and two large barren areas where restoration was begun—but couldn't be completed—in 2004.

Followup Actions and Lessons Learned

Some minor restoration work probably will continue in the area over the next several years, but it will probably be completed by wilderness rangers during routine patrol.

Lessons Learned

- Blasting trees (figure D–19) was an extremely effective restoration method, particularly in areas where rocks and fallen logs were not readily available. This technique was especially helpful at larger campsite areas where it would have been difficult to discourage visitor use otherwise. This technique produced immediate results.

Figure D–19—Strapping explosives to trees.

- Not only did blasting provide fallen logs, it also provided mulch materials (tree bark, needles, branches) for ground cover.
- Blasting maintained the wilderness character, leaving a natural appearance rather than saw marks on smooth stumps and the ends of logs.

Report submitted by:
Jennifer Ebert, wilderness resource manager
Desolation Wilderness Area
Eldorado National Forest, Pacific Ranger District

Appendix E—Forms

This appendix includes eight forms you can modify to fit your own needs:

- **Site Assessment Form**—This form can be used to prepare a detailed site assessment. The form was developed by Glacier National Park.

- **Campground Vegetation Inventory**—This form will help you assess individual campsites for restoration treatments. The form was developed by Glacier National Park.

- **Restoration Daily Project Log**—This log provides a daily record that will prove invaluable for planning other projects when you need to estimate how much time is required to complete certain tasks.

- **Onsite Restoration Information**—This form can be used to document initial restoration treatments. The form was developed by the Wenatchee National Forest's Wenatchee River Ranger District.

- **Restoration Site Maintenance and Monitoring Record**—This form will help you document ongoing maintenance and monitoring. Data recorded here may supplement data on the revegetation monitoring form. This form was developed by the Wenatchee River Ranger District.

- **Revegetation Monitoring Form**—This form tracks vegetative recovery. It was developed by the Wenatchee National Forest's Wenatchee River Ranger District.

- **Seed Collection Form**—This form documents the attributes of each seed lot. It was developed by the Wallowa-Whitman National Forest. A similar form can be developed for other types of plant material.

- **Plant Material Transportation, Storage, Extraction, and Preparation Log** (excludes seed)—This form is used for shipping plant materials to nurseries and tracks the steps taken to process the materials. The form was developed by the Forest Service's Pacific Northwest Region nursery program.

Site Assessment Form

Site name and location: ____

Date: ____

Examiner's name: ____

General description of site (include history and use): ____

____

____

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____

Site location (Section, township, and range or UTM): ____

____

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____

____

Elevation: ______________ Aspect: ________________ Slope/relief: ____

____

Soils and Geology

Soil type: ( ) Alluvial, flood plain, beach soils ( ) Wet soils ( ) Glacial soils

( ) Bedrock soil—metamorphic ( ) Bedrock soil—sedimentary

Soil description (from Natural Resources Conservation Service soil survey):_____________________________________

____

____

____

Characteristics of soil profile:

O—Organic layer:	Depth _______	Texture ___________	Color ___________	% Rock/gravel ________
A—Surface layer:	Depth _______	Texture ___________	Color ___________	% Rock/gravel ________
B—Subsurface layer:	Depth _______	Texture ___________	Color ___________	% Rock/gravel ________

Soil surface cover (total should equal 100%): Bare soil _____ Gravel ______ Rock (> 3 cm diam.) ______ Litter ______

Wood ______ Moss/lichen _____ Basal vegetation ______ Other ______

Describe soil surface status:

( ) Soil surface is stable; vegetation cover is adequate to prevent erosion in excess of natural rates.

( ) Soil surface is stable but vegetative cover is inadequate and increased erosion is likely.

( ) Soil surface is unstable because of trampling (compaction) and vegetation loss.

( ) Soil surface is unstable because of steepness, trampling, and vegetation loss.

Describe erosion type (rill, gully, slump, etc.), cause, and depth/extent over the site: ________________________________

____

____

____

____

General Vegetation Composition and Structure

Habitat type: ____

____

Community area: ( ) Upland ( ) Alpine/subalpine ( ) Wetland/riparian ( ) Other ______________________________

____

Dominant cover form: ( ) Aquatic species ( ) Broadleaf trees ( ) Conifers ( ) Shrubs ( ) Herbaceous cover

( ) Krummholz ( ) Moss/lichens ( ) Nonvegetated (rock or scree) ( ) Other __________________________________

____

Dominant species in upper layer (> 6.5 ft): ____

____

Dominant species in middle layer (2.5–6.5 ft): ____

____

Dominant species in lower layer (< 2.5 ft):____

____

Life form size—Dominant trees:

% seedling (< 1.0 in d.b.h.) ______ % sapling (1–4.9 in d.b.h.) ______ % Pole (5–8.9 in d.b.h.) ______

% medium (9–20.9 in d.b.h.) ______ % large (21–32.9 in d.b.h.) ______ % very large (33+ in d.b.h.) _____

Life form size—Dominant shrubs: % low (< 2.5 ft)_____ % medium (2.5–6.5 ft)_____ % tall (6.5+ ft) _____

Structural class:

( ) Stand initiation: growing space is reoccupied following a stand-replacing disturbance

( ) Stem exclusion/open canopy: ground-level competition limits establishment of new tree seedlings; primarily medium or smaller trees

( ) Stem exclusion/closed canopy: establishment of new tree seedlings limited by competition for light and resources

( ) Understory reinitiation: initiation of younger tree stand as older trees occupy less than full growing space; dead trees present; two or more canopy strata

( ) Young multistrata: multiaged stand with a mix of tree sizes and canopy strata; no large trees

( ) Old forest multistrata: multiaged stand with a mix of tree sizes and canopy strata; includes large, old trees

( ) Old forest single-stratum: broken or continuous canopy of large, old trees; understory absent with only a few seedlings or saplings

Microclimate: ( ) Not applicable ( ) Cold-air drainage or frost pocket ( ) Upslope warm airflow

( ) Wind-blasted environment that maintains vegetation in deformed state

( ) Snow catchment area that retains snow 2 to 4 weeks longer than surrounding areas with the same aspect

Special features: ( ) Not applicable ( ) Talus ( ) Scree ( ) Avalanche chute

( ) Wet meadow, grass dominated; surface wet in spring, moist in midsummer

( ) Marsh, sedge dominated; soil surface wet in midsummer

( ) Swamp, shrub dominated

( ) Bog mire, mosses, acidic wet peat soil

( ) Fen mire, reeds/sedges, alkaline wet peat soil

( ) Swale, depression/bench with no surface water, but moist soil evident in vegetation type

( ) Seep, depression/bench with surface water and vegetation found in moist environments

( ) Community adjacent to surface water (within 3 vertical feet and 100 horizontal feet of lake, stream, pond, etc.)

Vegetation change:

( ) Community is stable; will not change significantly in canopy closure, structure, species composition; similar to climax community

( ) Community is seral and changing toward climax community; will change significantly in canopy closure, structure, and species composition

( ) Community is changing away from climax community; will change significantly in canopy closure, structure, and species composition

( ) Community is seral and stable; dominant species will not change significantly

( ) Cannot tell if community is changing

Forest health:

Describe general vigor of tree species present, history of disease or obvious decline in health of tree populations, any signs of disease/pest infestations (conks, punk knots, stem decay, cankers, boring dust, pitch tubes, dead terminals, needle casts, flagging, etc.) : ____

____

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____

Exotic species present (species and abundance) and control recommendations: ___________________________________

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____

____

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____

____

____

Rare Species and Cultural Resources

Species of special concern: Identify any endangered or threatened species or species of special concern that are present:

Species name: ________________________________ Percent cover ______________________________________

____

Section 7 consultation in reference to the Endangered Species Act required before mitigation? ( ) Yes ( ) No

Cultural resources: Enter the type of feature or structure (house, barn, firering, archeological site, etc., and the name, if known: ____ _________________

____

____

Section 106 consultation in reference to the Historic Preservation Act required? ( ) Yes ( ) No

Animal Use

Describe animals using or frequenting the site (horses, cattle, other stock, elk, deer, moose, bighorn sheep, beavers, bears, rodents, raptors, other birds, lions, wolves, etc.). Is this site a known travel corridor for wildlife (identify species)? ________

____

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Disturbance History

Check the types of disturbance that have impacted this site:

( ) Understory burn ( ) Wildfire with suppression activities ( ) Prescribed fire (planned ignition)

( ) Prescribed fire (unplanned ignition) ( ) Herbicide application ( ) Other weed removal activities

( ) Recreational foot traffic, day use ( ) Camping ( ) Stock use ( ) Browsing ( ) Rodents

( ) Game trails ( ) Forest diseases ( ) Insect infestation ( ) Other ____________________

Disturbance intensity: ( ) Not applicable ( ) Low (5–20% bare ground)

( ) Moderate (20–40% bare ground) ( ) High (40–100% bare ground)

Describe visible impacts (exposed roots, damaged or scarred tree trunks, broken limbs, felled trees, etc.):

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Estimate size (square feet) of area requiring treatment: ____

Rehabilitation Recommendations

Site management recommendations (closure, use restrictions, etc.): ____

____

____

____

Describe previous rehabilitation work and results: ____

____

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____

Site and planting preparations (describe recommendations for scarification, soil amendments, mulch, etc.):

____

____

____

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____

____

Plant salvage (list species in the area available for salvage—define strategy for lifting and storage):

____

____

____

____

Soil salvage potential and borrow sites available (describe soil resources available and quantify any deficits, if applicable):

____

____

____

____

____

Barriers necessary to restrict use: ( ) None needed ( ) Fence ( ) Vehicle barrier ( ) Brush or logs ( ) Signs ( ) Rocks ( )

Other ____

Describe where barriers are needed: ____

____

____

____

____

____

Suggested revegetation species and quantity from site:

Trees	**Shrubs**
Forbs	**Grasses**

Plant materials collection and propagation recommendations:____

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Comments for project implementation: ____

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Species Inventory

Abundance—Indicate whether the species is D (dominant), F (frequent), or O (occasional).

Native trees	Abundance	Revegetative species

Native shrubs	Abundance	Revegetative species

Abundance—Indicate whether the species is D (dominant), F (frequent), or O (occasional).

Native grasses	Abundance	Revegetative species

Exotic forbs	Abundance	Revegetative species

Abundance—Indicate whether the species is D (dominant), F (frequent), or O (occasional).

Native forbs	Abundance	Revegetative species

Exotic grasses	Abundance	Revegetative species

Campground Vegetation Inventory

Name of campground: ____

Date: _________________________ Reported by: ____________________________

UTMs—Mapping notes: ____

____

____

____

Measurement of impact: ____

Description of soil condition (topsoil depth, color, organic matter and litter content, and any other notable features):

____

____

____

Dominant vegetative species: ____

____

____

____

Suggested revegetation species: ____

____

____

Suggestions for further restoration (including materials list):

____

____

____

Site No. 1

UTMs—Mapping notes: ____

____

____

Measurement of impact:____

Description of treatment implemented:____

____

____

____

Description of soil condition (topsoil depth, color, organic matter and litter content, and any other notable features): _______

____

____

____

Dominant vegetative species: ____

____

____

Suggested revegetation species: ____

____

____

____

Suggestions for further restoration (including materials list):__________________________________

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____

____

Site No. 2

UTMs—Mapping notes: ____

____

____

Measurement of impact:____

Description of treatment implemented:____

____

____

____

Description of soil condition (topsoil depth, color, organic matter and litter content, and any other notable features): _______

____

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____

Dominant vegetative species: ____

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____

Suggested revegetation species: ____

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____

Suggestions for further restoration (including materials list):

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Site No. 3

UTMs—Mapping notes: ____

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____

Measurement of impact:____

Description of treatment implemented:____

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____

Description of soil condition (topsoil depth, color, organic matter and litter content, and any other notable features): _______

____

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____

Dominant vegetative species: ____

____

____

Suggested revegetation species: ____

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____

____

Suggestions for further restoration (including materials list):

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____

Site No. 4

UTMs—Mapping notes: ____

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____

Measurement of impact:____

Description of treatment implemented:____

____

____

____

Description of soil condition (topsoil depth, color, organic matter and litter content, and any other notable features): _______

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____

Dominant vegetative species: ____

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____

Suggested revegetation species: ____

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____

Suggestions for further restoration (including materials list):

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Pit Toilet (Low Rider)

UTMs—Mapping notes: ____

____

____

Measurement of impact:____

Description of treatment implemented:____

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____

Description of soil condition (topsoil depth, color, organic matter and litter content, and any other notable features): _______

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____

Dominant vegetative species: ____

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Suggested revegetation species: ____

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Suggestions for further restoration (including materials list):

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Food Hanging Pole

UTMs—Mapping notes: ____

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____

Measurement of impact:____

Description of treatment implemented:____

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____

Description of soil condition (topsoil depth, color, organic matter and litter content, and any other notable features): _______

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Dominant vegetative species: ____

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Suggested revegetation species: ____

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Suggestions for further restoration (including materials list):

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Other notes or comments:

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General condition of campground—condition of all facilities, such as hitchrails, food hanging poles, toilets, etc.:

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Restoration Project Daily Log

Date:_________

Hours worked:______________

Crew:____

____

____

Number of visitors (people/stock/groups):

____

____

Campsites occupied (by site number and how many other occupied sites are visible from each occupied site):

____

____

____

Accomplishments:

____

____

____

____

____

____

Comments and observations:

____

____

____

Onsite Restoration Information

(Use this form to document initial restoration treatments)

Location:____

Restoration site and segment:____________________ Date:____________________

Approx. plot size:________________________ Observer:____

1. Method of site preparation (stabilization and soil treatments):

____

____

____

____

2. Type of plant material:

a) Wildling plugs (number and species present)

____

____

____

____

b) Seeding (species and amount seeded)

____

____

____

____

c) Nursery stock (number by species/stock type)

____

____

____

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____

____

____

____

4. Local materials used:

a) Boulders ____

b) Logs____

c) Stumps cut flush to the ground____

3. Sketch restoration site on back: include size, location, trails and photopoints.

4. Remarks:____

____

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____

Restoration Site Maintenance and Monitoring Record

Site:_____ Site segment:______

Location:____

Date:__________ Person taking observations:____________________________

Signs/stakes	
Erosion control blankets	
Erosion	
Human disturbance	
Weeds (nonnatives)	
Seedlings: Number by species Average diameter (in) Seeding and/or flowering (Y or N)	

Additional seedlings added: Species, number, location	
Wildling plugs added: Species, number, location	
Additional seeds added: Species, location	
Other native seedlings identified: Number, species, location	

Document any additional or extensive work on the reverse side.

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Revegetation Monitoring Form

Location____

Plot No._______ Date________ Observer____

Species	No. of plants	Vigor class[1]	Coverage class[2] (total for plot by species)
____________	____________	____________	____________
____________	____________	____________	____________
____________	____________	____________	____________
____________	____________	____________	____________
____________	____________	____________	____________
____________	____________	____________	____________
____________	____________	____________	____________
____________	____________	____________	____________
____________	____________	____________	____________
____________	____________	____________	____________
____________	____________	____________	____________
____________	____________	____________	____________
____________	____________	____________	____________
____________	____________	____________	____________

[1]Coverage classes:

(1) 0–5% (2) >5–25% (3) >25–50% (4) >50–75% (5) >75–100%

[2]Vigor classes:

(1) Plants appear unhealthy, probably not able to reproduce.

(2) Plants appear essentially healthy, but do not appear to be able to reproduce.

(3) Plants appear healthy, plants apparently spreading, but may be reproducing only vegetatively.

(4) Plants appear to be sexually reproducing, plants spreading.

(5) Plants appear robust, reproducing sexually, population spreading.

Seed Collection Form

*Asterisk indicates data that does not have to be recorded in the field. This information can be added later, but be sure to do so.

1. Scientific name____

2. Common name____

3. *Species code___________ 4. *Seed lot code____________________

5. *Watershed name and code____________________ 6. *Subwatershed name and code__________________

7. *Legal description____________________ 8. *Quad name__________________

9. Road number(s)____

10. Creek or site name____

11. Directions to relocate the area:____
____
____
____
____

(Attach a quad or road map of the collection area on the back of the form)

12. Elevation(s)________________ 13. Slope(s)______________%

14. Aspect(s) (N, S, E, W)__________

15. Habitat description(s)________________________

16. Plant association(s)____

Name (Use key or leave blank)

17. Number of plants in each population________________________

18. Number of populations in this seed lot______________________

19. Collector's name____

20. Collection date_____________ 21. Hours spent collecting______________

22. Comments____

Drying and Transport

23. *Drying method________________________ 24. *Drying time_________

25. *Nursery name_________________________ 26. *Date shipped_______

27. *District contact person ____________________________

Seed Collection Form Instructions

1. Scientific name: Be absolutely sure of the identification. Use the names in standard floras for area.
2. Common name: Use the names from standard floras for the area or those used in stand exams.
3. Species code: This is the code used for stand exams. Use the **correct** four- to six-letter code. Leave this field blank if you don't know the code.
4. Seed lot code: This code is from Nursery Lot Form 158. See the instructions accompanying that form.
5. Watershed name and code: Get a map of these names and codes from the district hydrologist.
6. Subwatershed name and code: Get a map of these names and codes from the district hydrologist.
7. Legal description: The township, range, and section from which the seed was collected. More than one entry may be needed for large batches of seed.
8. Quad name: The U.S. Geological Survey quad map name. More than one entry may be needed for large batches of seed.
9. Road number(s): List the main roads closest to the area where the seed was collected.
10. Creek or site name: General name of the area.
11. Directions to find the area: These can be fairly general.
12. Elevation(s): If more than one population is included, give the range of elevations, or list each elevation.
13. Slope(s): If more than one population is included, give the range of slopes, or list each slope.
14. Aspect(s): If more than one population is included, give the range of aspects, or list each aspect.
15. Habitat description: General habitat information, such as meadow or forest.
16. Plant association: Use the appropriate guide to determine the association name. If more than one population is collected, list each association name. If in doubt, leave this field blank.
17. Number of plants in each population: Estimate the number of plants that were harvested in each population. This line will have just one entry because it will be the same for all populations in a seed lot.
18. Number of populations in a seed lot: Number of populations, separated by 1/4 mile, where seed was collected.
19. Collector's name: The person (or persons) who did the collecting.
20. Collection date: Date the material was collected. Important for tracking success rates.
21. Hours spent collecting: Time spent actually collecting seed (not traveling).
22. Comments: Any extra information that may be helpful.

Drying and Transport

23. Drying method: Record whether the seed was dried in sun or shade and how the seed was dried.
24. Drying time: How many days the material was dried.
25. Nursery name: Name of the nursery where the material was sent.
26. Date shipped: Date the material was sent to the nursery.
27. District contact person: Name of the person the nursery should contact if there are any questions.

Plant Material Transportation, Storage, Extraction, and Preparation Log (Excludes Seed)

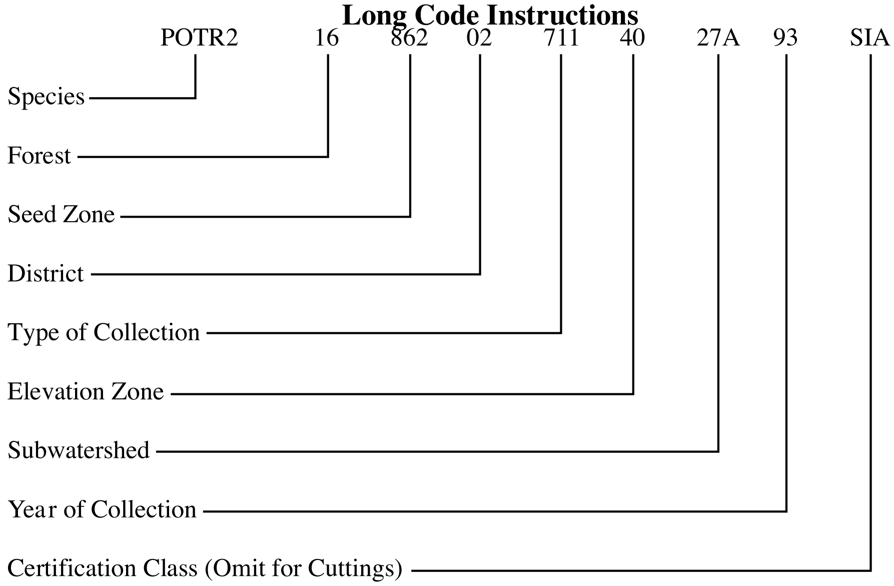
A. Completed at collection site	B. Completed at nursery
1. Collection site log No.:______________	12. Date received:___________________
2. Geographic ID: (creek, lake, trail, etc.)	13. No. of plant materials received: __________
____________________________________	14. Received by:_____________________
3. Forest:_____________________________	(name)
4. Ranger district:_____________________	15. Nursery log-in No.:_________________
5. Date shipped:_______________________	16. Storage of plant materials:
6. No. of plant materials shipped: ___________	Building:_____________________________
(whips, roots, bulbs, etc.)	Bay:_________________________________
7. Transport mode:___________________	Tier:_________________________________
8. Shipped by whom:__________________	Rack:________________________________
9. Shipping destination:________________	Tubs/buckets/etc.______________________
10. History:	17. Nursery preparation date:___________
Collection date:_____________	a) No. of cuttings
Insect/disease damage:________________	Length of cuttings:_________________
Storage of materials:___________________	Minimum caliper:___________________
11. Contact persons:___________________	18. Root or bulb preparation: ___________________
E-mail and phone:_____________________	19. Dip treatments for storage: ___________
	Date dipped:______________________
	20. Pre-sow dips:_____________________

C. Completed at the Collection Site and Verified by the Nursery

Species type:____

21. Plant material lot code (Use large, written numbers, the **long code**)

Long Code Instructions



Species: This is the four- to six-digit alpha/numeric code for the scientific name of the plant. Refer to PNW Publication *Northwest Plant Names and Symbols for Ecosystem Inventory and Analysis* (PNW General Technical Report PNW–46; 1976). If you only know what genus it is, fill in the first five letters of the genus; for example SALIX or RIBES.

Forest: A two-digit numeric code. For the Wallowa-Whitman this will always be 16.

Seed Zone: Zone of origin.

District: A two-digit numeric code.

Type of Collection: The *Forest Service Handbook* states that numbers from 700 and up will be used for non-seed collections. For hardwood cuttings this number will always be 711.

Elevation Band: These elevation groupings are in 500-foot bands, and the code is the first two digits of the upper limit of each band.

2,000-2,500 = Band 25

2,500-3,000 = Band 30

3,000-3,500 = Band 35

Year of Collection: A two-digit numerical code for the year. 1993 = 93.

The nursery fills in the entries below.

Treelot short code:___________________

Date planted:_______________________ 0–1:_________ 0–2:________________

No. of days callused:____________________

22. Inventory amount:__________________

23. Lifting date: __________________ Packing date:____________________

24. Net pack:__________________ Package by:___ Box _____Bag _____Both

25. Ship date:________________ Shipped by: ____ Refrigerated truck _____ Hot trailer

Other (specify):________________________

Nursery treelot number: ______

26. Remarks from nursery for forest/collection site followup:

a. Section A of form not completed or not completed correctly ______

b. Plant material of very poor quality, should **NOT** have been collected ______

c. Plant material damaged, apparently stored, or shipped under unsatisfactory conditions ______

d. Plant material collected at wrong time of year ______

e. Plant tags not completed in compliance with instructions ______

f. Plant material lot not on inventory plan or exceeds planned amount ______

g. Plant materials not packaged properly ______

h. Too much debris mixed with plant material ______

i. Individual lots not properly segregated on shipping vehicle ______

j. Other (specify) ______

About the Authors

Lisa Therrell is a wilderness manager on the Okanogan and Wenatchee National Forests in Washington. She also has worked as a wilderness planner, wilderness ranger, park ranger, and educator. Lisa has a bachelor's degree in biology and environmental studies. In her spare time, she can be found botanizing and gardening, as well as teaching yoga and enjoying outdoor pursuits. For over 20 years, planning and implementing restoration projects has been the most rewarding part of Lisa's job.

David Cole, Ph.D., is a research scientist with the Aldo Leopold Wilderness Research Institute in Missoula, MT. He has been studying the ecological impacts of wilderness recreation for 30 years. Recently, he has been working to find more effective ways to restore damaged sites.

Victor Claassen, Ph.D., wildland restorationist, teaches at the University of California Davis in the Land, Air, and Water Resources Department of the College of Agriculture and Environmental Sciences. He grew up on a family farm in Kansas and has always had soil in his veins. Victor is especially interested in soil fertility in wildland systems.

Chris Ryan, wilderness specialist, is the wilderness, wild and scenic rivers, and outfitters program leader for the Forest Service's Northern Region in Missoula, MT. She has worked in some of the Forest Service's finest wilderness areas throughout her 25-year career.

Mary Ann Davies is a project leader at the Forest Service's Missoula Technology and Development Center (MTDC). She received a bachelor's degree in mechanical engineering with a minor in industrial and management engineering from Montana State University in 1988. She worked in the Forest Service's Pacific Northwest Region with facilities, tramways, recreation, and fire. Before coming to MTDC in 1998, she worked 5 years with the Rocky Mountain Research Station's fire chemistry and the fire behavior groups in Missoula, MT. Mary Ann works on projects in the facilities, fire, recreation, and watershed, soil, and air programs.

Library Card

Therrell, Lisa; Cole, David; Claassen, Victor; Ryan, Chris; Davies, Mary Ann. 2006. Wilderness and backcountry site restoration guide. Tech. Rep. 0623–2815–MTDC. Missoula, MT: U.S. Department of Agriculture Forest Service, Missoula Technology and Development Center. 394 p.

This comprehensive guide focuses on restoration of small-scale impact caused by human actions in wilderness and backcountry areas. The guide's goals are to:

- Help practitioners develop plans that thoroughly address the question of whether site restoration is the best management action and, if so, develop a site-specific restoration plan that incorporates ecological concepts and addresses patterns of human use.
- Provide the latest information on site-specific restoration techniques, including site preparation, soil amendments, planting, mulching, and so forth.
- Explore the various methods of plant propagation both on and off a restoration site.
- Provide approaches for project monitoring and documentation.

Techniques discussed in the guide do not rely on motorized tools or mechanized transport, although those options may be mentioned. Examples are drawn primarily from the Western United States. Many of the techniques could be used in other settings. The laws regulating wilderness management and the philosophy guiding it are considered when discussing whether restoration activities are appropriate in areas designated as wilderness.

Keywords: bioengineering, cultural methods, disturbed land, disturbed soils, erodible soils, erosion, genetic diversity, genetics, handtools, monitoring, mulch, native plants, nurseries, philosophy, planning, planting, propagation, propagation materials, regulations, research, rooting, seeds, seed collection, soil amendments, soil physical properties, soils, tools, transplants, Western United States, wilderness management