Chapter 11

# Mountains

REGINA M. ROCHEFORT, LAURIE L. KURTH, TARA W. CAROLIN, JON L. RIEDEL, ROBERT R. MIERENDORF, KIMBERLY FRAPPIER, AND DAVID L. STEENSEN

This chapter concentrates on subalpine parklands and alpine meadows of southern British Columbia, Washington, Oregon, and western Montana. These areas lie on the flanks of several mountain ranges including the Olympics, the Cascades of Oregon and Washington, and the Coast Mountains in British Columbia (Figures 11.1 and 11.2).

## Ecological Characterization

Subalpine parklands and alpine meadows cover mountainous landscapes above the forest zone (Franklin and Dyrness 1987). Subalpine parkland is the broadest portion and is characterized by a mosaic of individual trees, tree clumps, and meadows (Henderson 1974, Franklin and Dyrness 1987). The lower boundary often is called forest line, which is the upper limit of closed contiguous forests (Douglas 1970, Rochefort et al. 1994). In this chapter, the upper limit of the subalpine parkland will be defined as the tree line, or the highest elevation at which erect trees grow. The alpine zone extends above the tree line and encompasses alpine meadows, krummholz, and areas of permanent snow and ice.

In the Pacific Northwest, the subalpine parkland is a broad ecotone, often 300 to 500 meters wide, characterized by scattered trees or tree clumps interspersed with herbaceous meadows (Franklin and Dyrness 1987). The forest line that forms its lower boundary varies with both latitude and aspect and generally lowers in elevation about 110 meters per degree of latitude (Franklin and Dyrness 1987). Typical forest line elevations range from 2,130 meters at Mt. McLoughlin in southern Oregon to 1,400 meters on Mt. Baker in northern Washington. Although depth and duration of snowpack are the predominant factors that maintain mountain meadows, their establishment may have been initiated by glacier recession or as a result of fires (Henderson 1974). Occasional fires in the closed canopy forest may also prevent the forest line from advancing upslope (Franklin and Dyrness 1987).

High-elevation herbaceous meadows are quite diverse spatially, with plant community patterns reflecting combinations of local slope, aspect, topography, and elevation. Physical characteristics of a site may change over very short distances, and although these differences may seem minor, they may result in steep gradients in soil moisture, temperature, and length of growing season (Billings and Bliss 1959, Canaday and Fonda 1974, Douglas 1970, Henderson 1974, Ingersoll 1991). Plants in upper mountain zones are well adapted to short growing seasons, low summer air and soil temperatures, high interannual variability in climate, and intense ultraviolet radiation. Perennial plants of short stature often dominate plant communities. The few annuals that do grow in this zone must be able to germinate, flower, and set seed within just

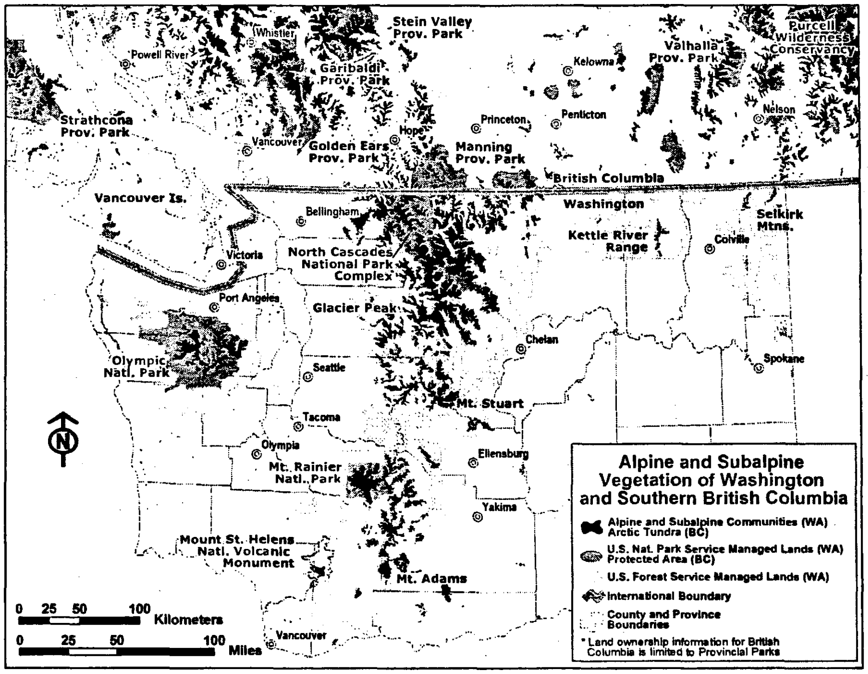



**FIGURE 11.1.** Map of alpine and subalpine areas in Washington and southern British Columbia. (*Compiled from Eng 2003, Washington Department of Fish and Wildlife 1999*)

a few weeks. Perennial plants often have high root/shoot ratios and have the ability to spread vegetatively to compensate for variable climatic conditions that may not favor sexual reproduction each year (Billings and Mooney 1968, Billings 1973). Nevertheless, plant populations often maintain high genetic variability and show surprisingly small-scale variation between populations in response to climatic gradients or random events (Linhart and Gehring 2003).

The mountains of the Northwest experience a maritime climate that includes long winters with moderate temperatures and abundant snowfall followed by short, cool summers with low precipitation. Thus, nearly all the moisture available for plant growth comes from melting snowpacks, which are greatly influenced by topography and elevation. Windswept alpine ridges often have little or no snow cover during the winter, exposing plants to desiccating winds, abrasion from snow crystals, and frozen soils. Although this results in longer snow-free periods, growing seasons are still short because of low soil and air temperatures. In addition, droughty, poorly developed soils often hold less soil moisture than protected sites with higher organic matter. Convexities or areas on the lee side of ridges or rock outcrops often have late-lying snowbanks with higher soil moisture but shorter growing seasons. Surface topography influences not only the distribution of plant communities but also the height of individual plants. Plant stems that protrude from snow cover during harsh winter winds are exposed to ice abrasion and desiccation and often die back. Restorationists must consider the mesotopographic gradients on adjacent, undisturbed areas and use these areas as references when reconstructing substrates on damaged sites and selecting target plant communities

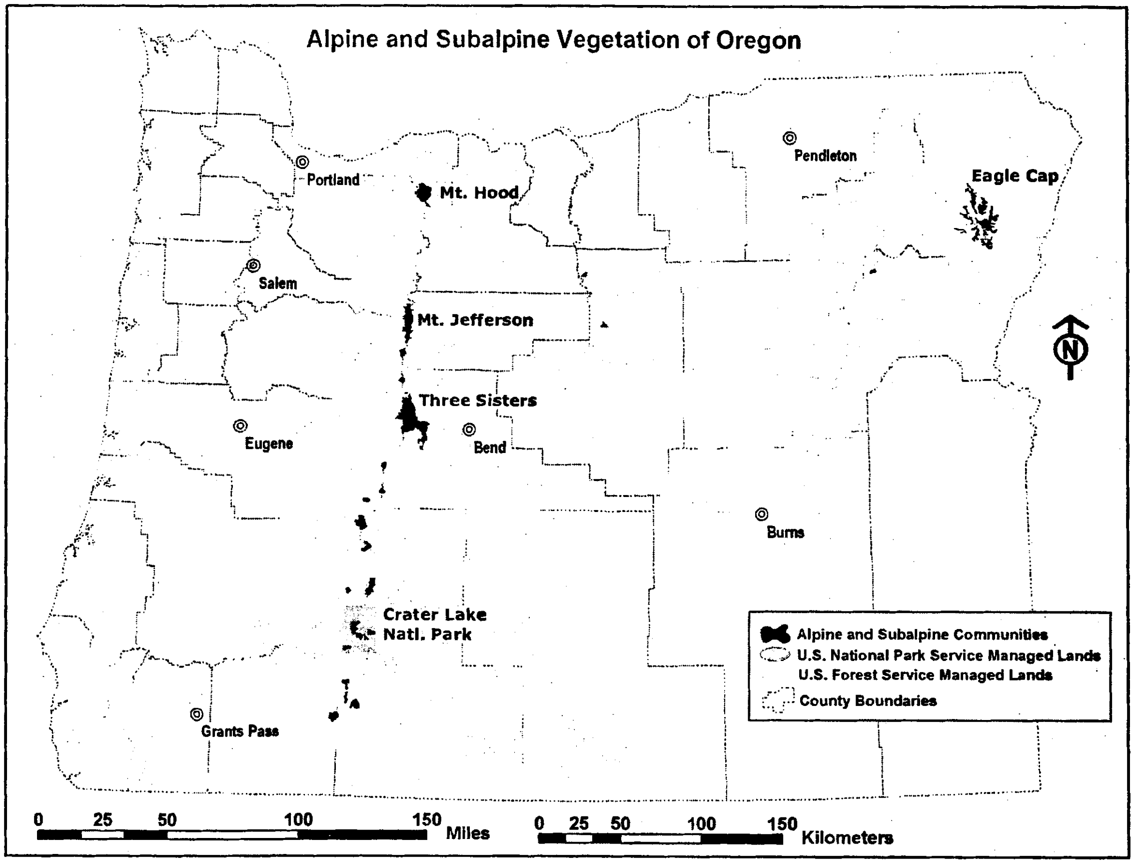



FIGURE 11.2. Map of alpine and subalpine areas in Oregon. (*Compiled from Kagan and Caicco 1992, Oregon Department of Forestry 2003, USGS 2003*)

## Plant Communities

Herbaceous meadow vegetation of the subalpine zone can be divided into five broad vegetation types (Douglas 1970, Henderson 1974, Franklin and Dyrness 1987). The first are heath–shrub communities dominated by one or two ericaceous shrubs, including red mountain heath (*Phyllodoce empetriformis*), cream mountain heath (*P. glanduliflora*), western cassiope (*Cassiope mertensiana*), and blueleaf huckleberry (*Vaccinium deliciosum*). The second group includes lush herbaceous vegetation dominated by tall perennials including Sitka valerian (*Valeriana sitchensis*), broadleaf lupine (*Lupinus latifolius*), and false hellebore (*Veratrum viride*). Third are low herbaceous vegetation communities dominated by fanleaf cinquefoil (*Potentilla flabellifolia*) and wooly everlasting (*Antennaria lanata*), often with lesser amounts of black sedge (*Carex nigricans*). Fourth are wet sedge types occupying topographic depressions, dominated by black sedge, showy sedge (*Carex spectablis*), alpine aster (*Aster alpigenus*), and wooly everlasting (*Antennaria lanat*). Last are dry grass communities found on well-drained sites more common on eastside mountains, dominated by green fescue (*Festuca viridula*), Idaho fescue (*Festuca idahoensis*), and broadleaf lupine.

Although many tree species are found in the subalpine zone, subalpine fir (*Abies lasiocarpa*) and mountain hemlock (*Tsuga mertensiana*) are the predominant species. Depending on local conditions, other trees common to this zone are Alaska yellow cedar (*Chamaecyparis nootkatensis*), whitebark pine (*Pinus albicaulis*), Engelmann spruce (*Picea engelmannii*), mountain larch (*Larix lyallii*), lodgepole pine (*Pinus contorta*), silver fir (*Abies amablis*), and Shasta red fir (*Abies magnifica* var. *shastensis*) (Franklin and Dyrness 1987).

Vegetation generally is more sparsely distributed across the alpine landscape than in the subalpine parkland. Growing seasons are generally shorter, summer temperatures are cooler, and precipitation is lower. Stronger winds blow snow off the ridges, exposing vegetation and soils to freezing winter temperatures. Alpine soils generally are drier than subalpine soils because they contain less organic matter and are less mature. Evidence of the harsher climate is easily observed in plant growth forms and species composition. Often plants are shorter and more compact (e.g., cushion plants), adaptations that facilitate survival in cool, windy environments where air temperatures decrease rapidly with distance above the ground surface. Leaves often are evergreen, are narrow, and have hairs or waxy surfaces to provide protection from desiccating winds or ultraviolet rays. Observation of these characteristics is important in planning restoration projects that involve transplants from other field sites or from greenhouses. For example, at Mt. Rainier National Park, mountain and pink heather plants were grown from cuttings for 4 years in a greenhouse. When the plants were transplanted one fall, they were noticeably taller than the adjacent heather plants in undisturbed communities. The next summer, most of aboveground stems of the transplants were dead, but fortunately new buds were sprouting from the root masses. The aboveground stems had been taller than the winter snowpack, even though they were only 6–8 inches high, compared with the existing 2- to 4-inch heathers. In this case, it would have been better to prune the top growth of these plants while they were in the greenhouse to promote more lateral growth and a plant form that was more similar to that of plants growing in the meadows.

Alpine plant communities of the Cascades and Olympics have been classified into five groups: snowbed, krummholz, heath–dwarf shrub, fellfield, and talus (Van Vechten 1960, Hamann 1972, Zwinger and Willard 1972, Douglas and Bliss 1977, Edwards 1980). Snowbed communities are found in areas closest to snowbanks and therefore have the shortest growing seasons. Snowbed community types range from the alpine buckwheat–tolmie saxifrage–luetkea (*Eriogonum pyrolaefolium–Saxifraga tolmiei–Luetkea pectinata*) described by Edwards (1980) in Mt. Rainier National Park, to six types dominated by various sedges or herbs in the north Cascades (Douglas and Bliss 1977). Krummholz consists of stunted trees that often are molded into a prostrate hedge in which individuals are indistinguishable. Krummholz mats can be composed of any species but often are subalpine fir, whitebark pine, Engelmann spruce, or mountain larch (Douglas and Bliss 1977). The heath–dwarf shrub types are found in areas with intermediate growing seasons and soil moistures between those of snowbeds and rocky ridge communities. These are dominated by a variety of shrubs, depending on local conditions. Pink, yellow, and mountain heathers and western cassiope generally are found on moister, more protected sites than willows (*Salix cascadensis*, *S. nivalis*), crowberry (*Empetrum nigrum*), or kinnikinnick (*Arctostaphylus uva-ursi*) communities. Fellfield and talus are found on the sites with the longest snow-free seasons and the least summer soil moisture. Fellfields are communities in which vegetation patches are interspersed with rocks or small pebbles. Quite a few have been described, ranging from the sparse vegetation of the creamy mountain heath ridge community (Edwards 1980) to the more continuous sedge turf communities dominated by Brewer and showy sedge (*Carex breweri*, *C. spectablis*, *Pedicularis contorta*) or grass species such as purple reedgrass (*Calamagrostis purpurascens*) and timber danthonia (*Danthonia interme-*

*dia*). In these communities, size and distribution of rock cover are extremely important factors influencing conditions for plant germination and establishment. Soils in alpine zones are subject to continuous movement, known as cryopedogenic action, caused by the freezing and thawing of soil water that may result in downhill movement of saturated soils, rock sorting and patterned ground (e.g., rock stripes, sorted or unsorted nets; see Washburn 1956 for a more complete description), or needle ice. Across all these sites, small changes in topography, aspect, and rock cover represent major changes in habitat. Therefore it is important to note conditions in disturbed and reference communities to design a successful restoration project.

## *Soils*

Restoration of soils in damaged alpine and subalpine ecosystems presents challenges for several reasons. First, bedrock geology, parent soil material, and the age of landforms vary widely. Active geologic processes that affect soil formation include volcanism, glaciation, hillslope, fluvial, nival, eolian, and mass wasting. These processes are constantly creating new parent material, and stabilizing soils on steep, still active landforms can be very difficult. In the more recent geologic past, the activity of continental and alpine glaciers and meltwater has left a young landscape in much of the high-elevation region of southern British Columbia, Washington, Idaho, and Montana. Most high mountain landforms are less than 15,000 years old, and many are less than 1,000 years old. The recent retreat of glaciers since the late nineteenth century has left large tracts of terrain that have only recently been colonized by plants. Soil parent material generally is coarse-textured in mountain provinces, although fine-grained soil accumulates in and near small tarns, ridgetops, flat benches, and cirque basins from deposition of loess and volcanic ashes.

Second, climate variability and short growing seasons make restoration of soils difficult at high elevations. In the Pacific Northwest, climate variability is high in space and time, with pronounced summer and interdecadal droughts. Dry periods can lead to difficult moisture conditions late in growing seasons on south-facing slopes. Strong regional, local, and microclimate gradients result from distance from the Pacific moisture source, latitude, elevation, and aspect. In all regional mountain ranges, there are wetter west-slope and drier east-slope conditions. Large annual snowfall levels in the maritime climate of the west slope of the Washington–Oregon Cascades and British Columbia–Alaska Coast Mountains depresses snowline and results in a wide distribution of alpine and subalpine vegetation (Price 1981). Heavy snowfall may also contribute increased toxins (e.g., airborne mercury) and nutrients to soils. Drier and colder conditions prevail in the more continental climate of eastern slopes and more interior mountain ranges, such as the Blues and Bitterroots. The resulting rise in snowline causes a generally narrower band of alpine and subalpine vegetation, a transition that can occur within 75 kilometers. Gradients north to south also are fairly strong, as illustrated by the wider distribution of glaciers and alpine and subalpine zones farther north in the Cascade and Coast ranges (see Figures 11.1 and 11.2). At upper elevations and on shaded northerly aspects, higher moisture conditions and more frigid air temperatures have strong effects on soil formation. Wind also plays an important role in soil formation through desiccation and redistribution of snow. In general, desiccation is greatest on west- and southwest-facing slopes where snow melts off and evaporation is high. Loess, or wind-deposited sediment, can be an important parent material and a source of pollutants and nutrients.

Ecological restoration in mountain zones must begin with a good understanding of the distribution of soil types across the landscape and an understanding of soil-forming factors. A significant challenge is that soils have not been mapped in many subalpine and alpine areas of the Northwest. Although the National Park Service is beginning to develop geographic information system–based soil models for national parks in Washington, information is generally lacking for the Mt. Baker Snoqualmie National Forest on the west slope of the Cascades and in many other areas.

Alternative methods can substitute for the absence of preexisting soil maps. Ecological units and bio-geoclimate zones have been mapped at 1:100,000 scale for much of the United States and Canada (Ecological Stratification Working Group 1996, McNab and Avers 1994). Soil–geology–vegetation links described in these classification schemes can be useful restoration guides. Establishing these relationships is an important aspect of the soil mapping effort in U.S. national parks. Perhaps the most rigorous approach is to use a nearby undisturbed site as a reference.

Although no single soil taxonomy has been developed for North America, the Canadian system of soil taxonomy is closely related to that of the United States (Expert Committee on Soil Survey 1987). Both are hierarchical, and the taxa are defined on the basis of measurable soil properties. Perhaps the main difference between the two systems is that all horizons to the surface may be diagnostic in Canada, whereas horizons below the depth of plowing are emphasized in the U.S. system. This may be because 90% of Canada is not arable.

Great soil orders are the coarsest taxonomic classification in the U.S. soil mapping scheme (Buol et al. 1980). In the subalpine and alpine zones of the Pacific Northwest they include andisols, entisols, spodosols, mollisols, alfisols, and inceptisols. Andisols are particularly important because they form in volcanic ash deposits, which are widespread in mountains of the Northwest. The presence of ash imparts a specific texture and chemistry critical to many plants. Spodosols are well-developed soils found on older, more stable parts of mountain landscapes. They form beneath acidic duff layers, particularly mountain hemlock, and are easily recognized by their reddish and gray subsurface horizons. Mollisols are saturated soils that form in wet sedge– and grass-dominated meadows and seasonally dry tarns (small mountain lakes). They are identified based on higher pH and cation saturation. Alfisols form beneath deciduous vegetation, particularly hardwood-dominated communities. Like mollisols, they have high cation saturation and a higher pH than spodosols. Entisols form in recent glacial, mass wasting, or stream deposits. They are characterized by weak soil horizon development. Development of an ochric horizon can be difficult to distinguish from geologic material in entisols. Inceptisols have better-developed soil horizons than entisols and generally occur on slightly older landforms.

These great soil groups are further differentiated based on temperature and moisture regimes, chemistry, aspect, vegetation, and other factors. Soil temperature regimes found in the alpine and subalpine zones generally are quite cold and are classified as cryic, meaning a range of 0–8°C. Although patterned ground often is seen at higher elevations, warm summers prevent permafrost soil conditions.

Moisture regimes vary widely with aspect and microclimate, and mountains in the Northwest exhibit a full range of conditions, from very dry to saturated. This variability in temperature and moisture, along with other factors such as topography, results in the development of very complex soil patterns in mountain landscapes.

## Soil Impacts

Recreational activities, grazing, and resort development in high-elevation areas can result in easily visible loss of soil and vegetation cover, but also there are less obvious changes, including soil physical, chemical, and biotic factors. Physical factors include organic matter content, soil structure, bulk density, soil texture, and soil porosity. Chemical soil factors include total nutrients, available nutrients, pH, conductivity, cation exchange capacity, and organic matter content. Soil biota includes macroinvertebrates, microbial function, and mycorrhizae. Although changes occur at all elevations, high-elevation soils are more vulnerable to lasting damage because of harsh climatic conditions and the fact that they are less mature. Nearly all projects at high elevations must address the potential for soil compaction and erosion. If postproject soil erosion is still occurring, this may affect prioritization of ecological restoration projects. Soil erosion potential is a function of soil texture, aspect, slope, rainfall, snowmelt, vegetation cover, and duration of exposure. Vegetation cover reduces the rate at which water flows downhill, thus protecting against sheet erosion. As cover is decreased, water flow can accelerate and pick up more surface particles, resulting in increased erosion. Recreational trails that are built straight up or down a landform create a high potential for continued erosion, which increases with length and gradient. As water encounters soil, the process of soil erosion is a function of two factors: detachment and transport (Ripple 1989). Both are related to soil texture, or the percentage of clay, silt, and sand. In order for soils to erode, water must have enough energy to detach particles from the soil matrix and transport them down the slope. Clay soils have high cohesion rates that resist detachment, but once they get moving they are easily transported. Sandy soils are easily infiltrated by water and often are too large to be easily transported. Generally, soil erodibility decreases with a decrease in silt fraction (Wischmeier and Smith 1978). In Mt. Rainier National Park, subalpine restoration projects were rated and ranked for restoration using a local adaptation of the Universal Soil Loss Equation so that impacts most susceptible to continued erosion would become the highest priority for restoration (Rochefort 1989). Erosion potential may determine the need to include an erosion mat such as excelsior (and justify the expense). Restoration of social trails that run perpendicular to a steep hillslope may necessitate excelsior or straw mats to reduce erosion, but a flat campsite on the same soils may not need mats for erosion control, although they may be used to help moderate surface physical conditions.

## Geographic Extent and Past Uses of Pacific Northwest Alpine and Subalpine Lands

We often think of the Northwest as a mountainous landscape, but true subalpine and alpine ecosystems make up only a small portion of the region (see Figures 11.1 and 11.2). Altogether, less than 0.5% of Oregon and 5% of Washington lie above the continuous forest line. Nearly all of these lands are managed by public agencies, with very few areas under private ownership (Table 11.1). Because of the inaccessibility of high mountains, steep terrain, and lack of merchantable timber, most were not converted to other land uses with Euro-American settlement. However, changing climates have shaped these landscapes over the last

TABLE 11.1.

*Ownership of alpine and subalpine areas of Oregon and Washington.*

| Ownership | Oregon Hectares (%)[a] | Washington Hectares (%)[a] |
|---|---|---|
| Bureau of Indian Affairs | | 25,868 (3.0) |
| Indian Reservation | 5,656 (6.0) | |
| Bureau of Land Management | | 323 (<0.1) |
| U.S. Fish and Wildlife Service | | 1,148 (0.1) |
| National Park Service | 5,907 (6.3) | 235,721 (27.7) |
| U.S. Forest Service | 81,982 (87.6) | 562,519 (66.2) |
| State lands | | 13,901 (1.6) |
| Private lands | 51(<0.1) | 10,170 (1.2) |
| Total subalpine and alpine | 93,596 | 849,650 |
| Permanent snow and ice | 4,109 (4.4) | 55,113 (6.5) |
| Total area in state | 25,093,466 (0.4)[b] | 17,486,061 (4.9)[b] |

[a]Percentage of total alpine or subalpine area, within the state, under this management.

[b]Percentage of state that is subalpine or alpine.

10,000 years, and there is evidence that Native Americans also altered them.

Widespread archeological evidence suggests that Native Americans have continuously used Northwest mountain landscapes for most of the last 8,000–10,000 years, or since glacial retreat. However, the archeology of high-elevation landscapes is poorly known, and reliable radiometric dates are rare. The three oldest radiocarbon dates recovered from subalpine sites in Washington are approximately 6,250 years B.P. in the Goat Rocks Wilderness of the Washington Cascades (McClure 1989), 5,000 years B.P. in the Olympic Mountains (Bergland 1984), and 4,470 B.P. in the North Cascades (Mierendorf 1999). Surveys reveal extensive use of tundra areas by Native Americans for hunting and subsistence-related activities. In addition to the references cited here, other high-elevation archeological evidence is reported from the interior of southern British Columbia (Pokotylo and Froese 1983), the Cascades (Fulkerson 1988, Vivian 1989, Franck 2000, 2003, Reimer 2000), the Rocky Mountains of southern British Columbia (Choquette 1981), and western Montana (Reeves 2003).

Excavation of archeological sites has revealed remains of mountain goats, cooking hearths, and chipped stone debris, indicating a hunting tradition (Burtchard 1998, Mierendorf 1999, 2004). In the north Cascades, subalpine and alpine areas were the source of two types of stone tools used for more than 4,500 years (Mierendorf 2004). In the Coast Range of southern British Columbia, obsidian from Mt. Garibaldi has been recovered from dated contexts spanning the entire Holocene (Reimer 2003). Peeled cedar trees located in forests close to subalpine areas indicate the collection of these materials to make baskets for huckleberry gathering (Burtchard 1998). Oral histories relate the use of fire by Native Americans to improve hunting grounds and growth of huckleberries or other plant foods. In one study at Mt. Rainier, evidence may indicate that Native Americans occupied high-elevation sites during warmer climatic periods when fire frequency was higher (Nickels 2002). Further research is needed to determine whether Native Americans effectively shaped vegetation patterns of high-elevation landscapes and where these changes may have occurred.

## Climate Change and Shifting Mountain Ecosystems

Palaeoecological studies indicate that the early to mid-Holocene (9,000 to 5,000 years B.P.) was 1–3°C warmer and drier than today. Tree lines in southern British Columbia at that time were 60–130 meters higher than they are today (Whitlock 1992, Clague and Mathewes 1989, Clague et al. 1992). Other studies in British Columbia, Alberta, and northern California document additional periods in which tree lines went up or down by as much as 100 meters in response to shifting climates (Rochefort et al. 1994). Most general circulation models predict that annual temperatures will increase during the next century in response to increased levels of greenhouse gases, and with these climate changes high-elevation ecosystems can also be expected to shift again (Rochefort et al. 1994).

Tree establishment has been documented in many subalpine meadows of North America after the close of the Little Ice Age (ca. 1850). Increases have been documented in summers with above-average temperatures (Rochefort et al. 1994), after termination of grazing (Dunwiddie 1977, Vale 1981), and after fire (which could be related to both climate and human activity (Agee and Smith 1984, Little et al. 1994). Additionally, studies by Brink (1959) and Gavin and Brubaker (1999) have documented changes in herbaceous species in response to climate changes in subalpine areas.

## Need for Restoration in Alpine and Subalpine Zones

Recreation, mining, grazing, and introduced invasive species are the primary activities that result in the need for restoration in subalpine and alpine areas. Impacts can range from small, discrete campsites with minimal plant or soil loss to very large areas that have been completely reshaped to accommodate mining, campgrounds, highways, parking lots, ski runs, or other development. Increased demand for mountain recreation in the Northwest is growing along with urban populations. The population of Washington alone is expected to grow from 5.9 million in 2000 to 7.5 million in 2025. At current growth rates, counties in the Seattle metropolitan area (King, Pierce, Kitsap, and Snohomish) will grow from 3.19 million to 5 million in the next 25 years (Campbell 1996).

Global climate change in itself may not become a primary cause of mountain ecosystem degradation, but its predicted effects will influence the results of restoration programs and perhaps identification of reference communities or evaluations of program effectiveness.

Livestock grazing has been associated with Northwest ecosystems since the early 1700s, when Indians acquired horses from Spanish missionaries. Lewis and Clark saw at least 700 horses in a Shoshone village in western Idaho and thousands more in the adjacent hills (Galbraith and Anderson 1971). Although very few bison made their way into the Pacific Northwest, domestic cattle and sheep have been an important part of the Euro-American history and economy of this region. Cattle were moved from Vancouver, British Columbia to Neah Bay, Washington as early as 1792. By 1825, cattle were becoming an economic factor in the development of some areas of Oregon and Washington, and by 1844 sheep were introduced to Oregon. During this period of expansion, stock were grazed on open range because most areas were still owned by Native Americans. After the Homestead Act of 1863 and subsequent grants of land to railroads, settlers began fencing off lands, and open ranges became limited. By the mid-1880s many arid rangelands were showing signs of overgrazing, and private ownership of lands had changed the way cattlemen managed their stock (Galbraith and Anderson 1971). In 1897, forest reserves were established, and the federal government began to control grazing by requiring permits on public lands.

World Wars I and II placed increasing demands on land for cattle and sheep grazing in order to support the war effort. These demands were felt on all federal lands, not only those administered by the Forest Service. In 1918, the National Park Service received a ruling by the U.S. Food Administration that sheep grazing was incompatible with the mission of National Parks because of the damage it caused to native plants and animals and its interference with visitors (Catton 1996). Unfortunately, the superintendent of Mt. Rainier National Park had already issued a permit for cattle grazing (200 to 500 head) in the Cowlitz Divide area. Although late snow prohibited stockmen from bringing in cattle, the permit was reissued in 1918 along with a second permit for 500 head of cattle in Yakima Park. The Yakima Park permit was reissued in 1919 and 1920, even after substantial damage was noticeable to vegetation and extensive soil erosion observed (Catton 1996). When requests for grazing reemerged during World War II, the National Park Service conducted a system-wide survey that concluded that damages caused by grazing far outweighed the very limited food supply benefits (Catton 1996). Although the National Park Service was able to draw a line against grazing, this was not the case on national forestlands. Because the permit process was not initiated and enforced until after widespread grazing, many areas were severely degraded already. Grazing damage typically includes shifts in species cover from native plant communities to exotic grasses, soil compaction, and soil erosion. Development of soil terraces or soil pedestals is common in heavily grazed areas. In severely damaged areas, restoration must consider repair of both topography and plant communities. An important consideration in revegetation of these areas is whether aggressive noxious weeds are present, even in small quantities. Grazing may have promoted dominance of exotic perennial grasses, but removal of grazing may result in an increase in other species, so revegetation plans must carefully identify which will need to be removed or replaced.

Recreation use or development may also introduce nonnative species to alpine and subalpine ecosystems that can outcompete native plants or cause mortality. Introduced plants such as clover and Scotch broom have been documented on subalpine restoration sites in Mt. Rainier National Park for up to 20 years after restoration. There are also impacts from introduced insects or diseases on mountain plant communities. Whitebark pine is a keystone species of high-elevation ecosystems in western North America. It is an early successional species that establishes both on harsh ridges and in subalpine areas after fire. Today, its long-term survival is uncertain because of the introduction of a Eurasian blister rust (*Cronartium ribicola*) to North America in 1910 (Hoff 1992, Keane and Arno 1993, Campbell and Antos 2000, Kendall and Keane 2001, Zeglen 2002). Surveys in Washington, Oregon, and British Columbia have documented blister rust in about 90% of all stands examined. Mortality is around 20–30%, and average blister rust infection rates range from 13% to 46% (Campbell and Antos 2000, Goheen et al. 2002, Zeglen 2002, Murray and Rasmussen 2003, Shoal and Aubry 2004, Rochefort and Courbois in prep.). Mountain pine beetles and changes in fire regimes may also influence mortality in whitebark pine stands. Restoration or conservation plans to ensure long-term survival of whitebark pine are important for many high-elevation areas in the Pacific Northwest.

## Restoring Mountain Ecosystems

Restoration of high-elevation, mountain ecosystems follows the same basic steps as restoration in the other ecosystems covered elsewhere in this book, including site assessment, project planning, implementation, site protection, and monitoring. The specific methods used on a given project reflect not only the goals for the restoration site but also environmental conditions, including severity and extent of the impacts. This section provides a synopsis of each step of restoration as it applies to high-elevation areas and then illustrates application of these steps by discussing three general categories of restoration: small sites with minimal soil loss or substrate alteration (e.g., social trails or campsites), larger sites where geomorphic restoration is necessary, and restoration of a single species.

### *Site Assessment*

Site evaluation is the first step in any ecological restoration process and sets the stage for project goals, objectives, and monitoring. Site evaluation includes location, ecological characterization, quantitative description of impacts, and description of special considerations such as endangered species, habitat, current recreation use, and cultural resources. Ecological characterization should include defining the project boundaries, noting elevation, slope steepness, aspect, soil type, and vegetation communities. Description of impacts should include size and shape of impacts, vegetation damage, soil erosion, and any modifications to streams or water sources. Identifying the origin of the impacts and how management of the area may influence either development or maintenance of the site can influence the success of future restoration. Special concerns in the project area that will influence the ultimate success of the program may include rare species, cultural or historic areas of significance, and scenic vistas or other attractions that influence how people will continue to use the area. It is helpful to produce a map of the site illustrating the location of impacts, specific areas of concern, vegetation, water resources, and site access. In subalpine or alpine areas small-scale changes in topography can result in large differences in soil moisture availability, growing season length, and plant communities. These variations should inform the selection of revegetation methods, timing, and costs. For this reason, it may be helpful to produce a larger-scale map noting plant community changes along with the impacts, late snowmelt areas, ponds, streams, or areas of active erosion. For example, if a social trail traverses a heather community and a lush herbaceous meadow, the percentage of the impact in each plant community type will have a significant influence on the method of revegetation, so it will be important to record this and make it part of a restoration strategy.

## *Project Planning: Restoration Goals and Objectives*

Setting broad goals for a site regarding plant communities, topography, and use is key to a successful project. Broad goals establish a foundation on which to create more detailed objectives. Examples could include the following:

- Restoring original contours and hydrologic functions to a subalpine area that had earlier been regraded as a drive-in campground
- Full reestablishment of a subalpine meadow
- Revegetating bare ground with subalpine plants but leaving the imprint of previous roadbeds or altered contours

With broad goals in hand, project planning can proceed toward a conceptual plan and then a more detailed implementation plan. Sometimes a conceptual plan is developed to pursue funding or build support for a project. Once this support is gained and resources allocated, an implementation plan based on more detailed objectives can be developed. Several factors may influence both broad goals and detailed objectives, which may need refinement as the project moves forward. Examples of some factors that may influence objectives and goals are as follows:

- *Site location*: Is it in a designated wilderness, remote backcountry, or front country near a visitor center? Does the zone designation prohibit camping or other activities?
- *Sensitive resources*: Are there sensitive plant or animal species or habitats, archeological resources, or other cultural resources in the project area?
- *Protection of genetic integrity*: Is it important to protect naturally evolving levels of local genetic diversity or just to ensure that plant stock used in revegetation has been collected from similar environmental conditions (e.g., in seed zones)?
- *Surrounding matrix*: Is the restoration site located in a pristine landscape that provides intact reference communities and potential donor plants or propagation sources? Or, conversely, was the affected plant community locally unique, so that plant materials for revegetation will have to come from a more distant area?
- *Number, size, and severity of impacts*: Are the impacts small, discrete areas, such as campsites or social trails? Or are they large scale, such as a mine or former ski run that is now to be restored to a natural landscape but not necessarily the one that predated the disturbance?
- *Future use of the area*: If the area to be restored is at the edge of a road or on a ski run, long-term goals may include limiting plant height, and occasional mowing or other landscape management may be needed.
- *Cost of restoration and available funding*: Funding sources, labor, and overall costs of restoration may necessitate refinement of initial goals and objectives. Generally, costs and funding availability will influence primarily the methods and the timeframe of a project, but in cases of severe impacts, they may also influence broad goals.

These variables will help determine the extent to which a project aims for complete restoration or a preexisting site ecosystem, a native but not historic system, or mere stabilization that prevents further degradation.

## *Project Implementation: Site Preparation*

Site preparation involves all the work needed to prepare a site for revegetation, including scarification, stabilization, filling, and recontouring. The site assessment should note the extent to which vegetation cover has been lost, the degree of soil compaction, whether soil loss has occurred, and whether erosion is ongoing. If the impacts were of low intensity and short duration, soil may be compacted but still on site. In this case, scarification to a depth of 6–12 inches (15–31 centimeters) may be sufficient to increase soil aeration and permeability and facilitate successful revegetation. The objective of scarification is to break up hardened soil into small soil particles. Scarification may be accomplished in two steps, first breaking the soil into large chunks with a Pulaski, pick, or shovel and then further breaking it up by hand into fine particles.

Soil compaction or loss often results in sites that are below grade with respect to surrounding areas. These may need to be filled and probably stabilized. Sites that have lost less than 2 inches (5 centimeters) of soil often can be filled to grade without additional stabilization. In long, narrow areas, such as social trails, adding silt bars often is necessary. Silt bars are similar to water bars on developed trails, but they differ in two important respects. First, silt bars are built below the surface. Second, they are placed parallel to the contours of the site rather than at an angle. Silt bars can be composed of wood or rocks (Figure 11.3). Once silt bars are installed, the site can be filled to match surrounding grades (Rochefort 1990). If the restoration site is extremely large, as in the case of a road removal, a former mine, or other major development, recontouring of the site with heavy equipment may be needed, and stabilization may be accomplished through reshaping of the ground surface.

FIGURE 11.3. Erosion control bars being installed at Mt. Rainier. (*Photo by National Park Service*)

Adding soil means finding suitable sources of materials, and this can be challenging in alpine environments. The best soil sources will be close to the project site, but in many areas this is not possible because no new excavations are occurring. If the project involves removing a road, material sometimes can be pulled up from the fill slope to completely restore the original contours or at least soften the slopes and mask the original road cut. If soil loss is minimal and limited to the upper organic layer, it might be possible to incorporate imported peat into a scarified soil bed. In the case of old fire rings, it may be necessary to remove burned wood and ash, then scarify the site and add soil or organic matter. Peat is lightweight and easy to transport but is not a renewable resource, so its use should be kept to a minimum. If soil loss has been extreme, areas more than 12 inches (30 centimeters) below the desired grade can first be filled with rocks or gravel, with soil added on top. In this instance, rocks and gravel should be well tamped so that soil will fill only the spaces between the larger particles. In a project at Mt. Rainier National Park, a 3-foot (1-meter) deep social trail was filled first with rocks from a talus slope, then gravel, and finally soil placed on the upper 12 inches (15 centimeters). This site was near a late-lying snowbank, and one restoration objective was to restore sheet flow of snowmelt. However, because the soil had not settled between the larger rocks, there were hollow spaces that channeled water, apparently creating a subsurface stream. Much of the gravel was pushed up and deposited on the surface, creating an unusual soil horizon.

Imported soil should be as similar as possible in physical and chemical characteristics to the native soil. It should be steam sterilized to kill seeds of species exotic to the site.

Once a site has been filled to grade, the surface is reshaped. The filled areas should mimic the contours of the surrounding area. Imagine the flow patterns from local snowmelt. Perhaps the area should include a simulated stream bank or be designed to sheet flow. It is important to be certain that the soil surface is not too flat. Pristine subalpine and alpine areas have quite a bit of microtopography diversity, with many small depressions and convexities, each providing unique conditions for plant germination and survival. Rocks partially embedded in the soil surface provide protection from wind, provide shade and conserve moisture, and provide obstacles to slow or disperse surface water flow. In alpine or young subalpine areas (more recently released from glaciers or snowfields), surfaces often are covered with a "desert pavement" of small rocks or pebbles. This surface helps modify soil temperatures and protect young seedlings from wind and desiccation (Edwards 1980).

## *Revegetation*

Revegetation often is the most time-consuming component of mountain restoration, often occurring over many years. Revegetation methods include seeding, natural seed rain from adjacent areas, transplants from adjacent areas, greenhouse propagation and outplanting, and layering. Size of the disturbed area, distance to undisturbed plant communities, and project goals all help determine revegetation methods. Some important considerations are as follows:

- *Size of the impact*: The larger the disturbed area, the more likely it is that active revegetation techniques will be needed.
- *Intensity of impact*: This includes depth of compaction or erosion and loss of soil organic matter. Loss of soil may mean loss of natural seed banks or an inhospitable substrate for natural seed rain to do the job. Seed banks in subalpine areas normally are confined to surface soil layers and reflect local communities. Most subalpine species have only short distance dispersal capability (Weidman 1984). Highly eroded sites or sites where the organic layer of soil has been lost

probably will not have a seed bank that could provide new germination, even in scarified soils. Zabinski et al. (2000) found that seed density in seed banks declined exponentially with distance from established vegetation, and seed density increased with depth of organic matter. Therefore, the greater the impact, the more active planting is needed.

- *Adjacent plant communities*: Does the adjacent plant community contain species that might easily colonize the disturbed area through seed or vegetative growth? Lush herbaceous communities often contain lupines that produce quite a few large seeds that can successfully colonize bare soil. In contrast, mature heather communities contain few species that would be expected to volunteer or spread into adjacent disturbed sites. Environmental conditions and plant communities change over very short distances in high-elevation areas. Therefore, a detailed survey of plant communities or soil moisture levels may serve as a basis for a revegetation plan and methods.
- *Selection of seed and plant materials*: Direct seeding has been used with success on some projects, but seedling survival is higher on mesic sites, adjacent to rocks or plants that provide shade, associated with mulches or erosion mats, or in small depressions on the soil surface (Ramsay 2004, Juelson 2001, Moritsch and Muir 1993). Plants can be first grown in a greenhouse and transplanted to field sites (Rochefort and Gibbons 1992).
- *Protection of genetic integrity*: Collection of plants or seed from similar environmental conditions (slope, elevation, aspect) will increase survival, but it is best to collect materials within a very short distance from the site. Many high-elevation species are perennial, and seed production may not occur on an annual basis. High levels of variation within and between populations and the presence of ecotypes are evidence that sexual reproduction is an important process in mountain plant communities (Billings 1973, Gehring and Linhart 1992, Linhart and Wise 1997, Rochefort and Peterson 2001, Linhart and Gehring 2003). Linhart and Wise (1997) state that differentiation of herbs, in complex terrain, can be significant over distances of less than 100 meters. Although movement of tree seeds to sites 2–3 kilometers away may be reasonable, movement of herbaceous plants may need to be more conservative, perhaps on the order of hundreds of meters. Environmental factors such as elevation (within bands of 1–200 meters), precipitation, soil moisture, soil type, and aspect all may influence patterns of genetic diversity.
- *Genetic diversity*: Outcrossing species have high genetic diversity, but it helps to spread collection over several days and to collect from different microsites. Small depressions may contain individuals that are more adapted to wetter conditions. Greenhouse studies at Mt. Rainier National Park documented the possibility of genetic variation between seeds collected on different dates. Seeds of *Aster alpigenus* were collected on several dates in Paradise Meadows (approximately 5,500 feet elevation). When the seeds were treated and grown using the same methods, seeds from different seed lots grew at different rates. Because there is always uncertainty with respect to microsite conditions at restored sites, it is best to use plant material from close to the site while maintaining a high degree of within- and between-population diversity. When propagating plants from cuttings, collect them from many plants rather than just those with high growth rates. Where individual plants are difficult to distinguish (e.g., clonal species such as heathers), collect several cuttings (based on rooting success) per plant and then move about 1 meter to another plant to collect more. Cuttings should be taken from a minimum of twenty plants in a given collection.

A seed increase program may be useful in large areas or where protection of genetic integrity is important. Selection can occur in seed collection, field propagation, and location of the seed increase program. Plants that survive in seed increase fields must do well in an agricultural situation (i.e., fungicides and harvesting equipment), which are certainly different from their natural environment. When impacts are large, protection of genetic integrity may be downplayed in order to allow for economies of scale where adherence to a more rigorous standard would compromise the potential success of the project. In areas where there are no adjacent native communities, seeds may be collected from a different watershed. In such cases, finding areas with similar environmental conditions is the key. For instance, in many wilderness areas in the national park system, the goals include restoration of a functioning ecosystem, maintenance of genetic integrity, and continuation of overnight recreational use. Often, when impacts are small, such as individual campsites or social trails, goals are to restore the area to plant communities that probably would cover the site in the absence of impacts. If protection of genetic integrity is a high priority, this may limit the revegetation methods. Seed rain or vegetative spread of adjacent plants will provide the highest level of protection, although these options may be too slow to meet other objectives. A second option is to focus seed or plant collection in a small area adjacent to the site.

The spatial arrangement of planted material often is an important project consideration. Most revegetation projects include both transplants and seeding. Transplants provide instant cover and are visible evidence that restoration is under way. They also provide shelter for establishment of seedlings and an early seed source for further spread of plants. In small areas, plants should be distributed fairly evenly across the entire site. In the case of social trials or large sites, additional plants at access points might help dissuade recreational use and trampling. It is best to organize greenhouse plants or direct transplants in clumps. First, plants in groups appear to have higher survival rates and rates of spread, possibly because each plant has a protected aspect, and collectively they modify environmental conditions in their immediate area. Second, clumps of plants appear more natural to visitors and may assist in changing use patterns. Third, on large sites planting may take several years, and it is easier to add plantings between clumps than between individuals. If clumps of plants are distributed throughout and area, they can then provide seed sources all over.

Species selection is an important consideration. Subalpine and alpine plant communities are very diverse, even at the smallest scale. Reference communities provide models of species composition, relative dominance, and companion plant guidelines. For instance, in a wet sedge community black sedge and alpine aster are often are codominant, but cinquefoil, showy sedge, red mountain heather, and luetkea are present in smaller and more variable amounts. Greenhouse propagation may include all these species except heather, so planting guidelines are limited to the remaining species. Because black sedge and aster are codominant, planting guidelines for clumps might be seven to ten plants and three or four species. Black sedge or aster could make up two thirds of the total plants, with the remaining plants from the other species. Examples of this are four sedge, two aster, and two cinquefoil; two sedge, five aster, and two cinquefoil; or five aster, two cinquefoil, and one luetkea. There should also be guidelines for which species to plant singly or in clumps always greater than two. These guidelines may result from field observations, including size of plants available and expected growth rates (e.g., you can plant species that spread more slowly more densely than those with more rapid growth).

## *Timing of Planting*

In the Pacific Northwest, most moisture in high-elevation areas comes in the fall or winter and usually in the form of snow. Snowmelt provides most of the water for summer plant growth, so seeding and planting must be timed so the plants are in place to take advantage of snowmelt. The only exception is in sites that can be watered in summer. Planting in the fall also gives transplants time for root growth and allows seeds to undergo natural stratification.

### *Erosion Mats and Watering*

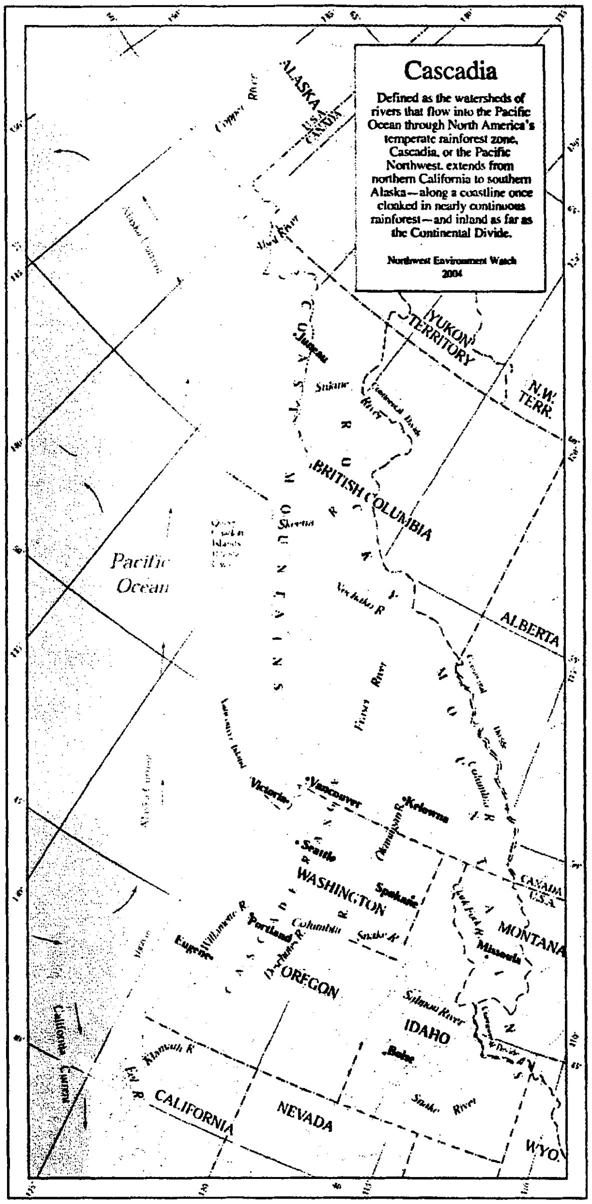
Erosion mats such as excelsior (aspen shavings), straw, or coconut fiber (coir) can be an important component of restoration. First, they modify soil temperatures and moisture levels. Second, they may help keep people off the restored site. Juelson (2001) evaluated the effects of watering and use of clear plastic on sites seeded with luetkea and black sedge, in the Enchantment Lakes of Washington. All plots were covered with an excelsior blanket. She found that double watering increased seedling emergence of the graminoids and that the plastic increased emergence of the luetkea. Similarly, Lester (1989) found that clear plastic increased seed germination of *Carex* species in North Cascades National Park. Using plastic necessitates checking the site frequently during the growing season and may require irrigation.

## Restoration Costs

Typically the cost of restoration shapes project goals and objectives and may determine whether a project is feasible at all. Caution is advised with regard to modifying goals. Those who develop cost estimates for restoration must understand the objectives and know which objectives are flexible and which ones are fixed. Recontouring an abandoned roadway may be essential for a successful project, whereas reducing planting density may affect only the length of time needed for restoration or recovery of the aesthetics of the site. To assess the impacts of reduced work in relation to cost savings, a cost estimate of the restoration necessary to meet the goals should be developed and then optional objectives negotiated or modified to fit available funding. For example, at Mt. Rainier National Park, there is an established standard of planting eight plants per square foot in subalpine meadows. The natural density in undisturbed meadows is approximately eighty plants per square foot on average. Cost estimates for subalpine meadows are based on a minimum planting density of eight plants per square foot. If this is beyond available funding, new planting density objectives are developed. Based on project goals, it may be determined that some areas will receive seeding only, some areas will have lower density, and some areas will receive the target density.

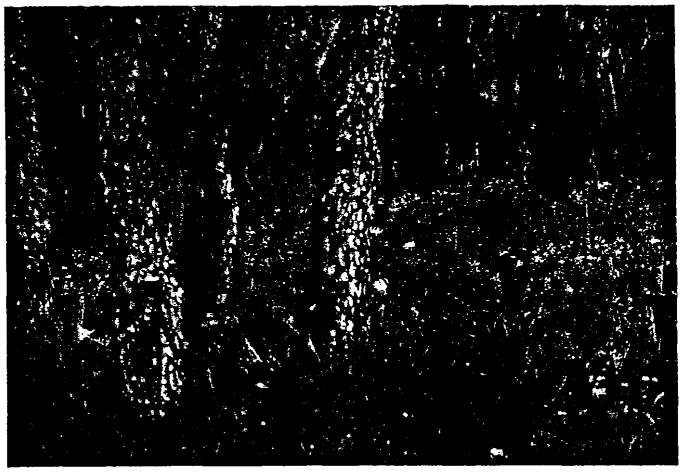
The first step in preparing a cost estimate is to distinguish fixed costs from flexible ones (Table 11.2). Fixed costs are those that are absolutely necessary to success and cannot be deferred. Negotiable costs may be critical to long-term success but can be put off for future funding or implemented at lower levels. Fixed and nonfixed costs may vary by project based on the goals, but in general site work and stabilization are fixed costs. Planting density, seeding density, and mulching are typical examples of nonfixed costs. However, if a key goal is to have an immediate aesthetic benefit, then planting density may best be treated as a fixed cost.

Restoration cost estimating can be done in several ways: itemization of each component, total cost per plant, or total cost per area (generally based on a total cost per plant). Itemization of each component is recommended for projects that involve contracting, sites where there is no restoration history on which to base costs, or sites that need complex site work before plant installation. Estimating costs on a per-plant or area basis is best used for areas where there is a history of restoration and costs can be easily developed, projects are routine, and little or no contracting is involved. When developing restoration costs it is important to consider all necessary costs, some of which can be hidden. Therefore, itemized cost estimating is recommended initially.

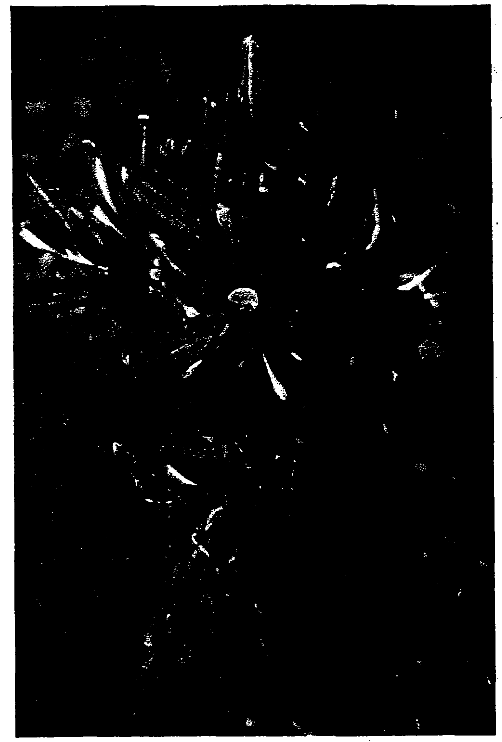



Map drawn by Cynthia Thomas on the basis of forest data in "Conservation International, Ecotrust, and Pacific GIS, Coastal Temperate Rain Forests of North America," Portland, 1995. See also David D. McCloskey, "Cascadia," Cascadia Institute, Seattle, 1998.

**PLATE 1.** This map of the Cascadia bioregion shows the main watersheds of the Pacific Northwest that flow through the temperate rainforest zone, from the Copper River in the north to the Eel River in the south, reaching east up the Snake River to Yellowstone National Park. (*Map drawn by Cynthia Thomas, using information from Conservation International, Ecotrust, and Pacific GIS. Used with permission from Northwest Environment Watch*)

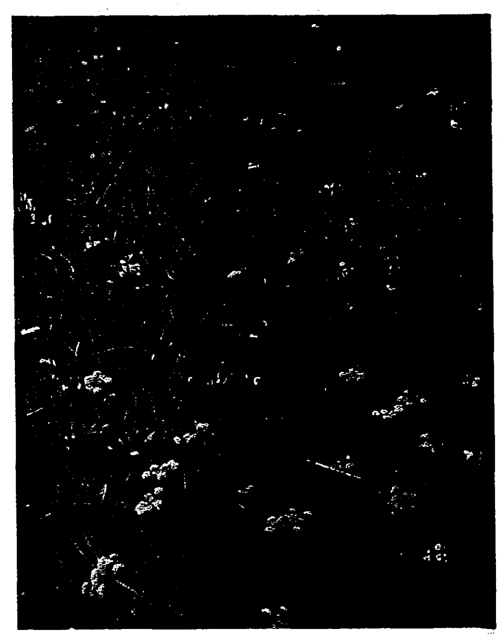


(a)



(c)

(b)



(d)

PLATE 2. Oaks.
*(a)* Spring bloom in the Garry oak savanna understory of British Columbia. (*Photo by Tim Ennis, The Nature Conservancy of Canada*)
*(b)* A woodland skipper (*Ochlodes sylvanoides*) pollinates *Aster curtus*. (*Photo by Tim Ennis, Nature Conservancy of Canada*)
*(c)* Common camas (*Camassia quamash*) bulbs, commonly found in prairie and oak habitats, was a significant Native American trade item, second only to salmon. (*Photo by Ed Alverson*)
*(d)* Indian hyacinth (*Camassia quamash*), desert parsley (*Lomatium mohavense*), and oval-leaf shooting star (*Dodecatheon hendersonii*) are among the forbs that make up the crayon-colored prairie palette in spring. (*Photo by Tim Ennis*)

(a)

(b)

(c)

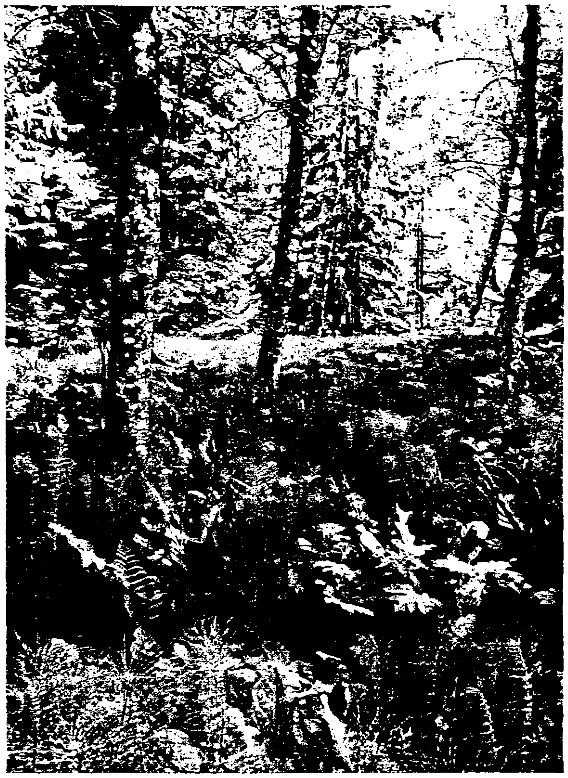
(d)

**PLATE 3.** Prairie.
*(a)* Perennial wildflowers are visually dominant in spring in this Willamette Valley prairie. (*Photo by Bruce Taylor, courtesy of Defenders of Wildlife*)
*(b)* Great camas (*Camassia leichtlinii*).
*(c)* Rosy checkmallow (*Sidalcea virgata*).
*(d)* Bog deer-vetch (*Lotus pinnatus*) is one of two lotus varieties commonly found in prairie habitats.

(e)

(f)

**Plate 3.** *(continued)*
*(e)* Willamette daisy (*Erigeron decumbens* var. *decumbens*) is listed as endangered throughout its range.
*(f)* Tough-leaf iris (*Iris tenax*).



(a)

(b)

PLATE 4. Freshwater wetland communities. (*All photos by Fred Small of Pacific Habitat*)

(*a*) Red alder—dominated forested wetland in central Washington Cascades, Mt. Rainier National Park.

(*b*) Low-elevation bog dominated by California pitcher plant (*Darlingtonia californica*) and Labrador tea (*Ledum glandulosum*).

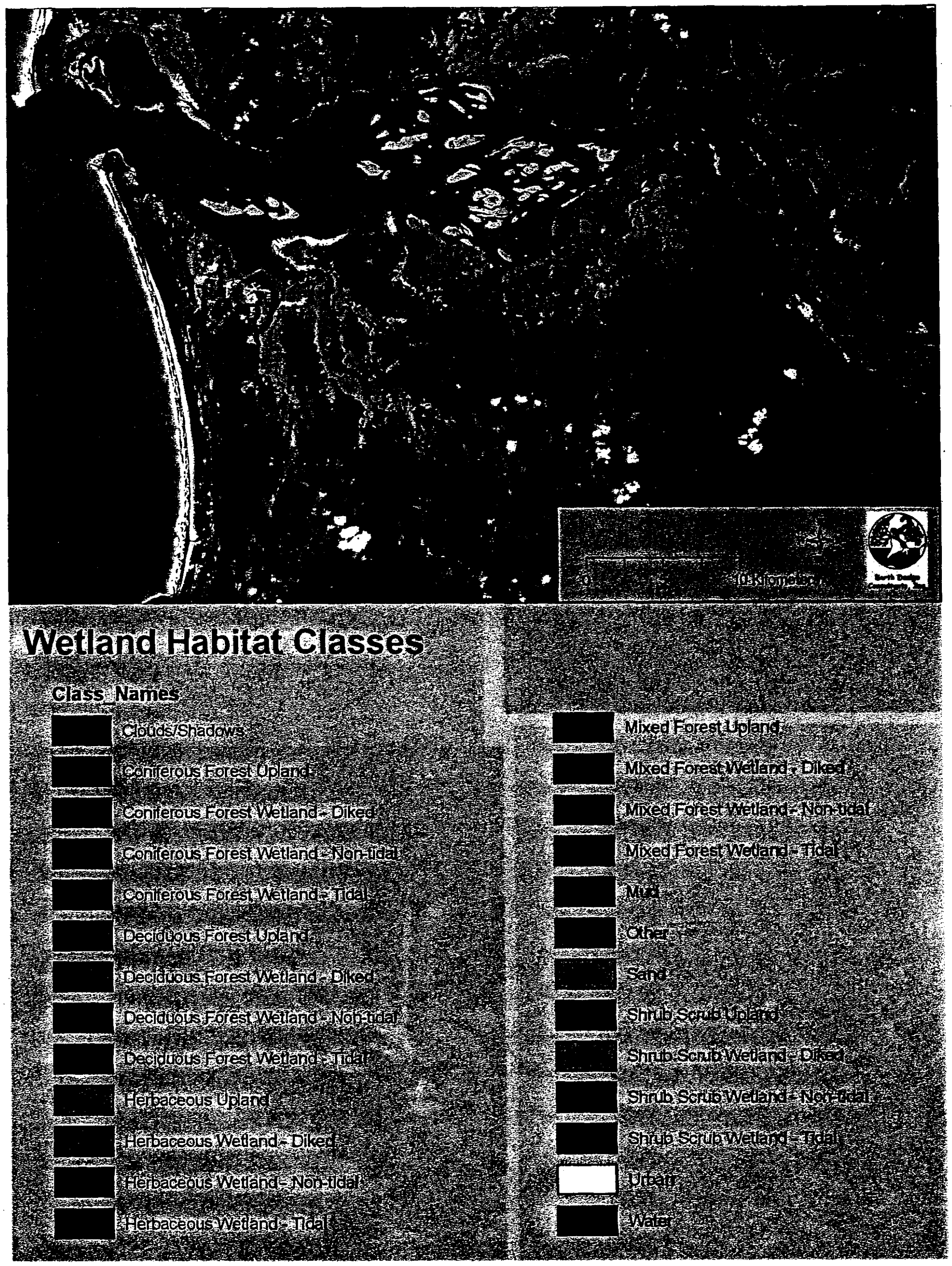
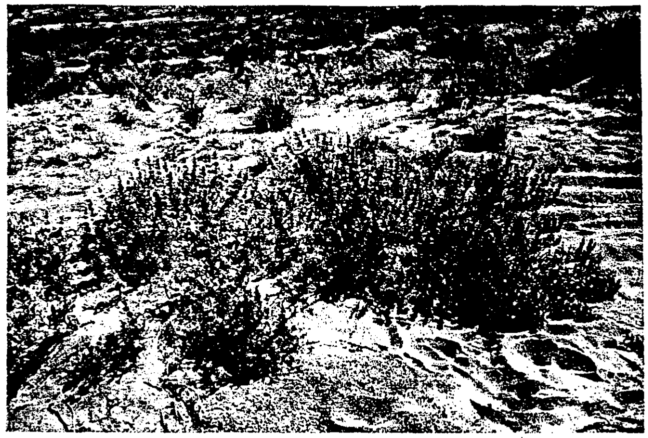



**PLATE 5.** Tidal wetlands. Habitat cover classes in the Columbia River Estuary. This landscape perspective is very useful for prioritizing and planning tidal wetland restoration and conservation efforts across a wide area. *(From Earth Design Consultants)*

(a)

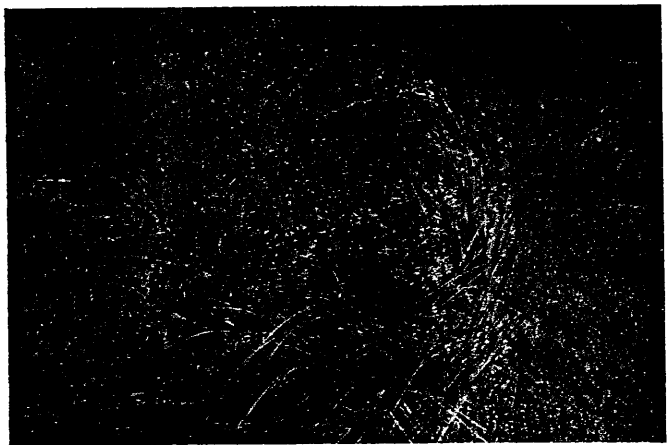


(c)

(b)

(d)

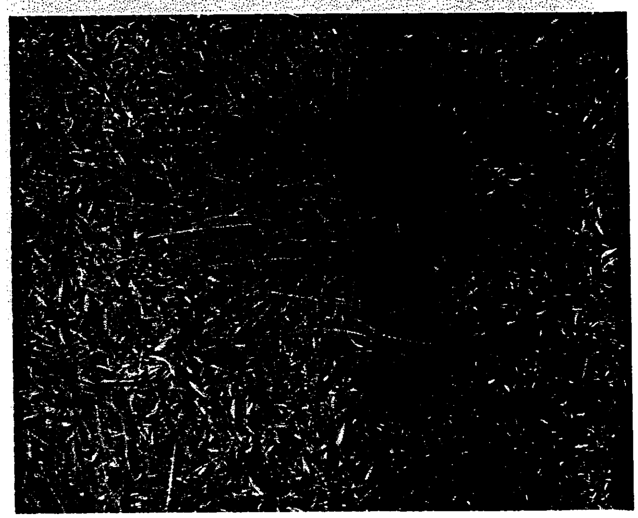
PLATE 6. Shrub steppe ecosystems. A sample of native species being restored to the shrub steppe.
(*All photos by Steve Link*)
*(a)* Big sagebrush (*Artemisia tridentata*).
*(b)* Bluebunch wheatgrass (*Pseudoroegneria spicata*).
*(c)* Purple sage (*Salvia dorii*).
*(d)* Pale evening primrose (*Oenothera pallida*).



**(e)**

**(f)**

**(g)**



**(h)**

PLATE 6. *(continued)*
*(e)* Indian rice grass (*Achnatherum hymenoides*).
*(f)* Bitterbrush (*Purshia tridentata*).
*(g)* Globe mallow (*Sphaeralcea munroana*).
*(h)* Sandberg's bluegrass (*Poa secunda*).

(a)

(b)

(c)

**Plate 7.** Ecosystem restoration at Mt. Rainier National Park. (*All photos by National Park Service*)
(*a*) A Paradise social trail site in 1986 before restoration.
(*b*) The same social trail site in 1987 after slope stabilization and initial planting.
(*c*) The same site in 2004, nearly indistinguishable from surrounding areas.

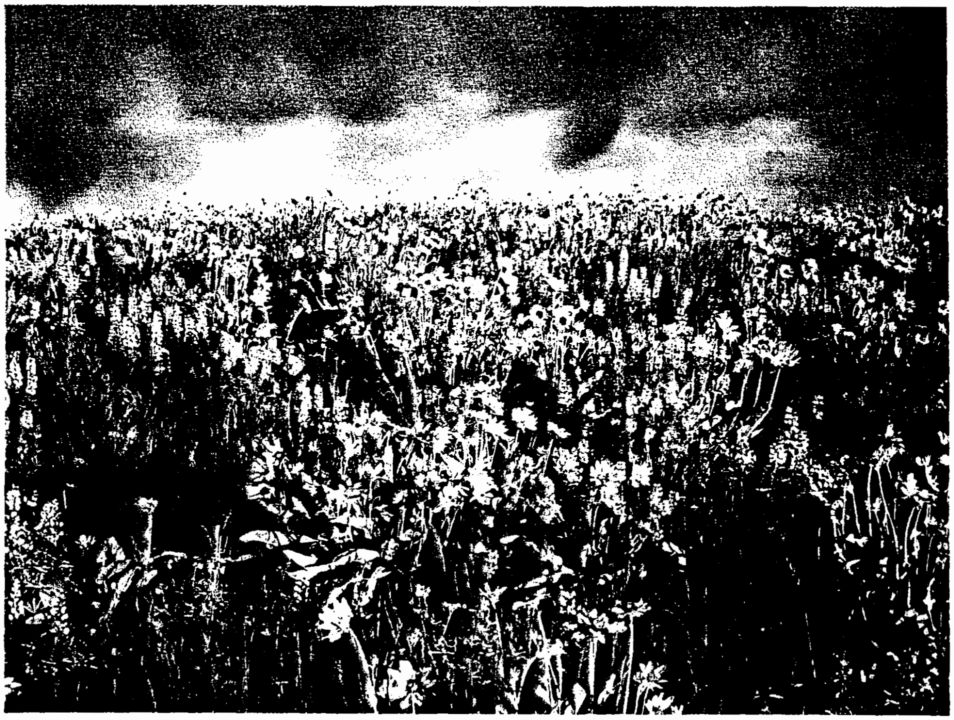


PLATE 8. Urban restoration examples.
*(a)* Native wildflower meadow in the Boise, Idaho foothills. (*Photo by Tim Breuer, Ada County Parks*)
*(b)* Garry oak on rock outcrop on Vancouver Island, in the Victoria, British Columbia urban area. (*Photo by Carolyn Macdonald, City of Saanich, British Columbia*)

**Plate 8.** *(continued)*
*(c)* Camas meadow near Portland, Oregon, restored through broom removal. (*Photo by Carolyn Macdonald, City of Saanich, British Columbia*)

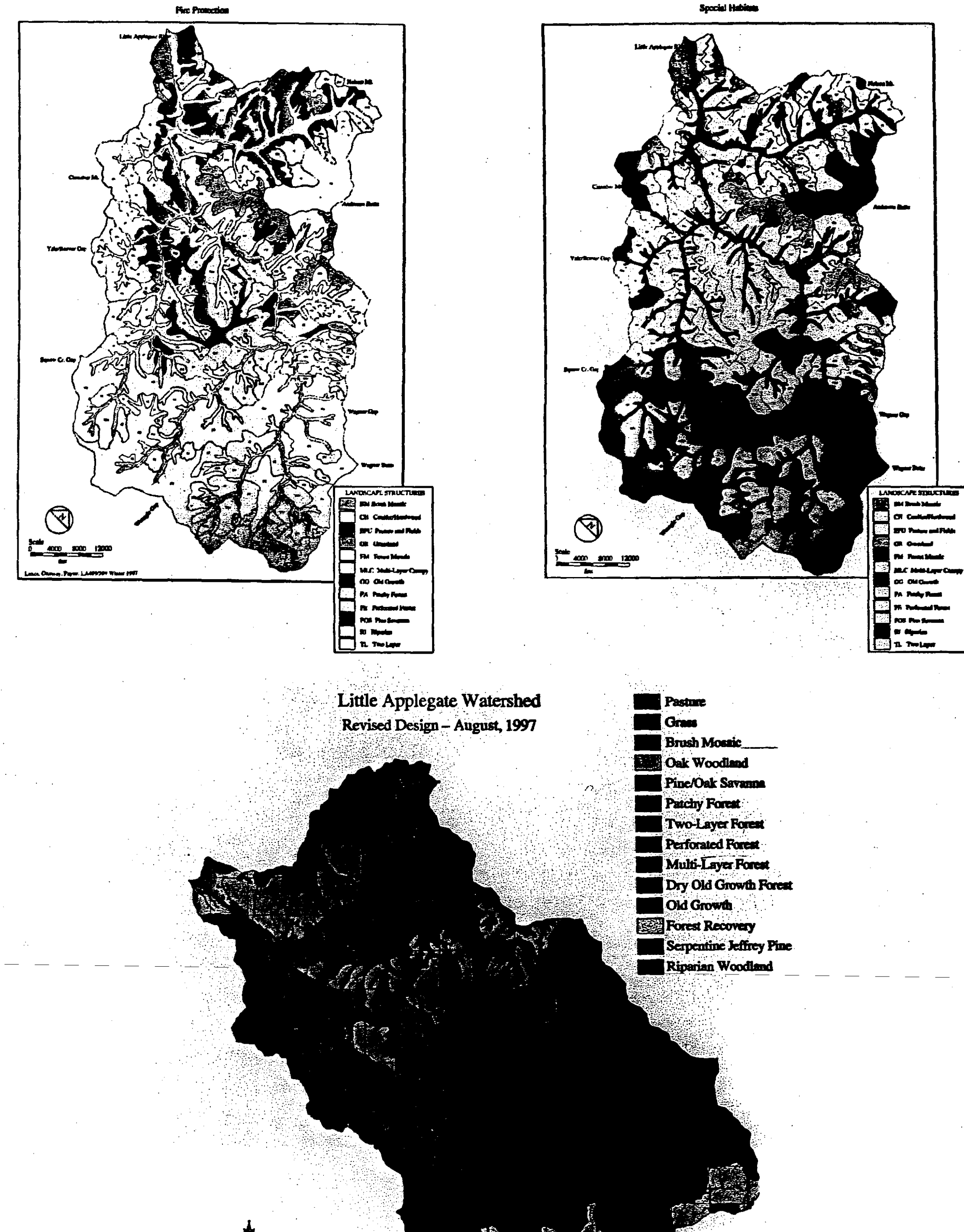


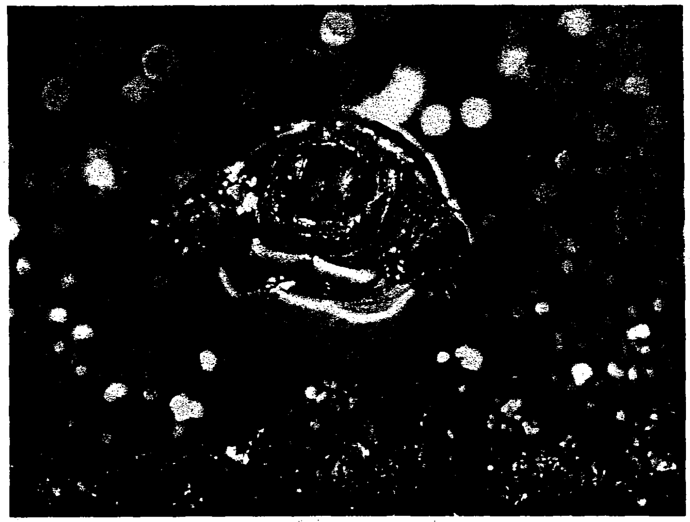

**Plate 9.** Watershed restoration.
*(a)* Little Applegate Watershed fire restoration emphasis areas. (*Courtesy of the University of Oregon Landscape Architecture Program*)
*(b)* Little Applegate Watershed old-growth restoration and other special habitat emphasis areas. (*Courtesy of the University of Oregon Landscape Architecture Program*)
*(c)* Final watershed design shows distribution of large-scale landscape structure types to guide restoration and continued resource extraction. (*Courtesy of the U.S. Forest Service*)

(a)

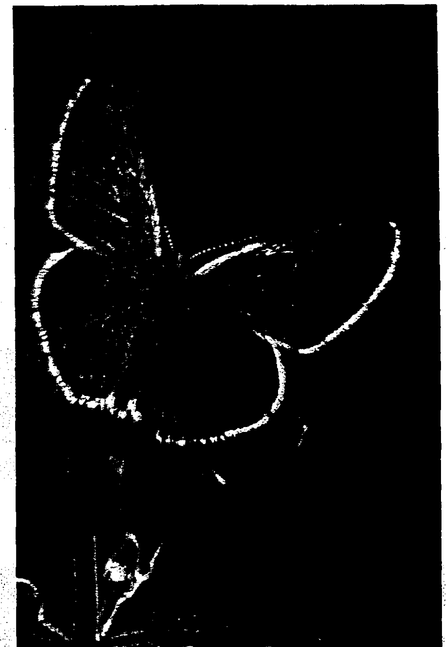
(b)

(c)

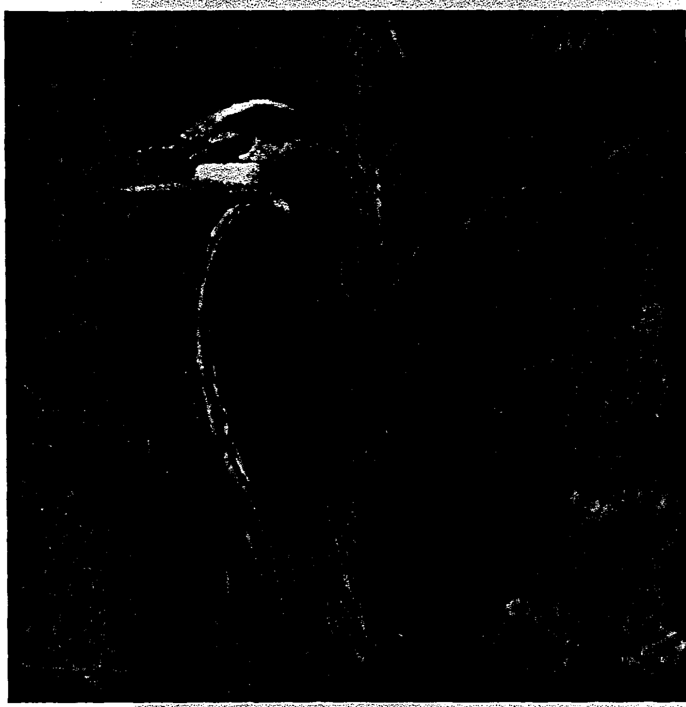
**Plate 10.** Wildlife restoration.
*(a and b)* White-breasted nuthatch (*photo by Bill Hubick*) and western bluebird (*photo by Nigel Milbourne*) both depend on mature oak woodlands and can use nest boxes as interim habitat.
*(c)* A gray wolf family unit in the Yellowstone area. Reintroduction of wolves has begun to reshape the ecosystem. (*U.S. Fish and Wildlife Service*)



(d)



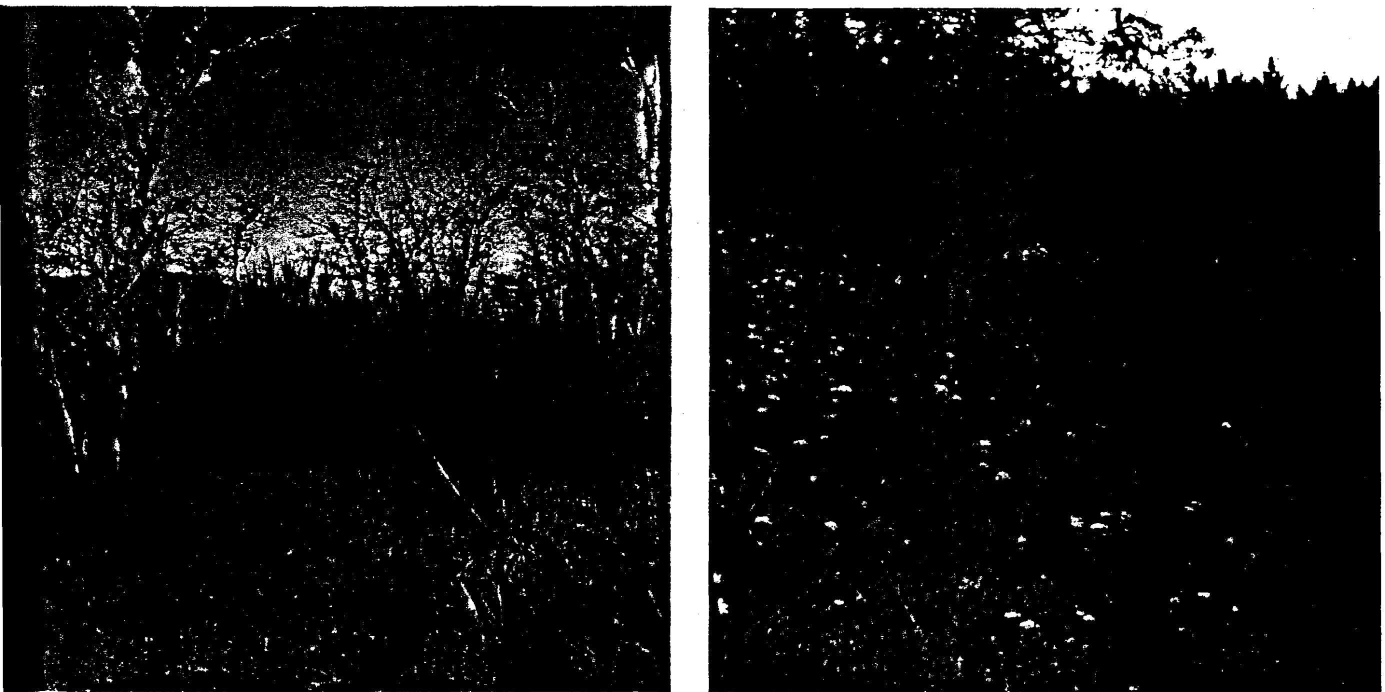
(f)



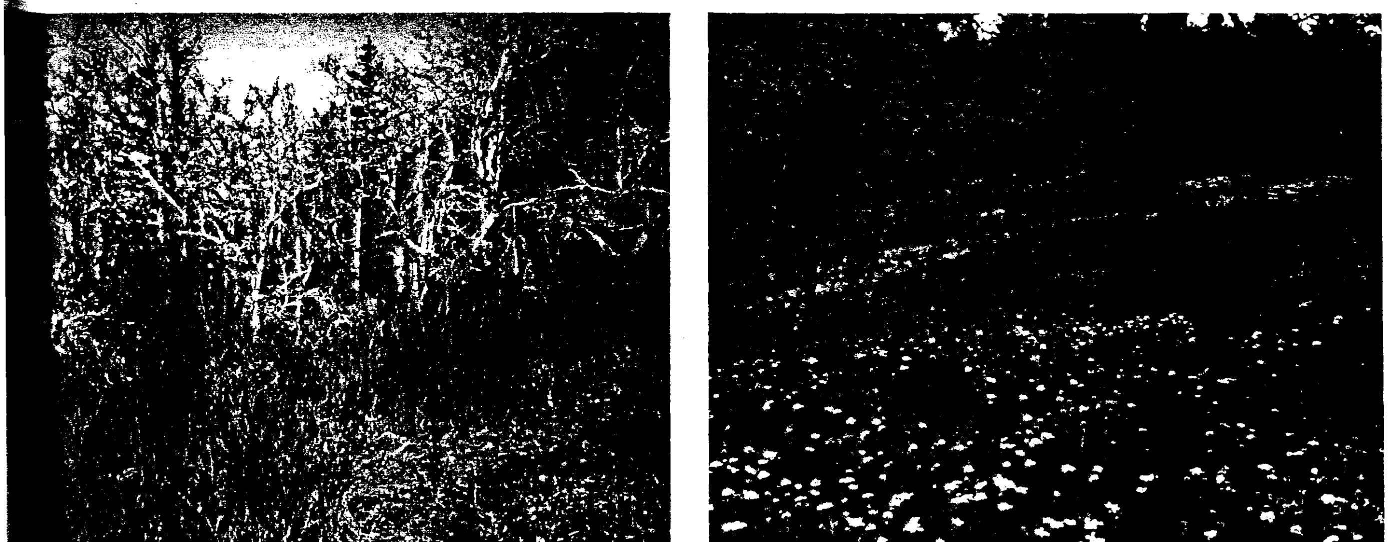
(e)

(g)

**Plate 10.** *(continued)*
*d)* Western pond turtle hatching at Fern Ridge in the Willamette Valley.
*(e)* Great blue heron, a species affected by the recovery of another, the bald eagle. (*Photo courtesy of Defenders of Wildlife*)
*(f)* Fender's blue butterfly, a species dependent on successful restoration and management of bunchgrass prairies. (*Photo by Alan D. St. John, Defenders of Wildlife*)
*(g)* Columbia Basin pygmy rabbit.



(c)



(d)

**Plate 11.** Invasive species. Removing Scotch broom to restore oak woodland and savanna at Mt. Tzouhalem on Vancouver Island. (*All photos by Dave Polster*)
*(a and b)* Before invasive removal, taken in 1992 and 1994, respectively, all too typical of Garry oak ecosystems.
*(c and d)* After 5 years of broom removal efforts, taken in 1999. Note recovery of native forbs.

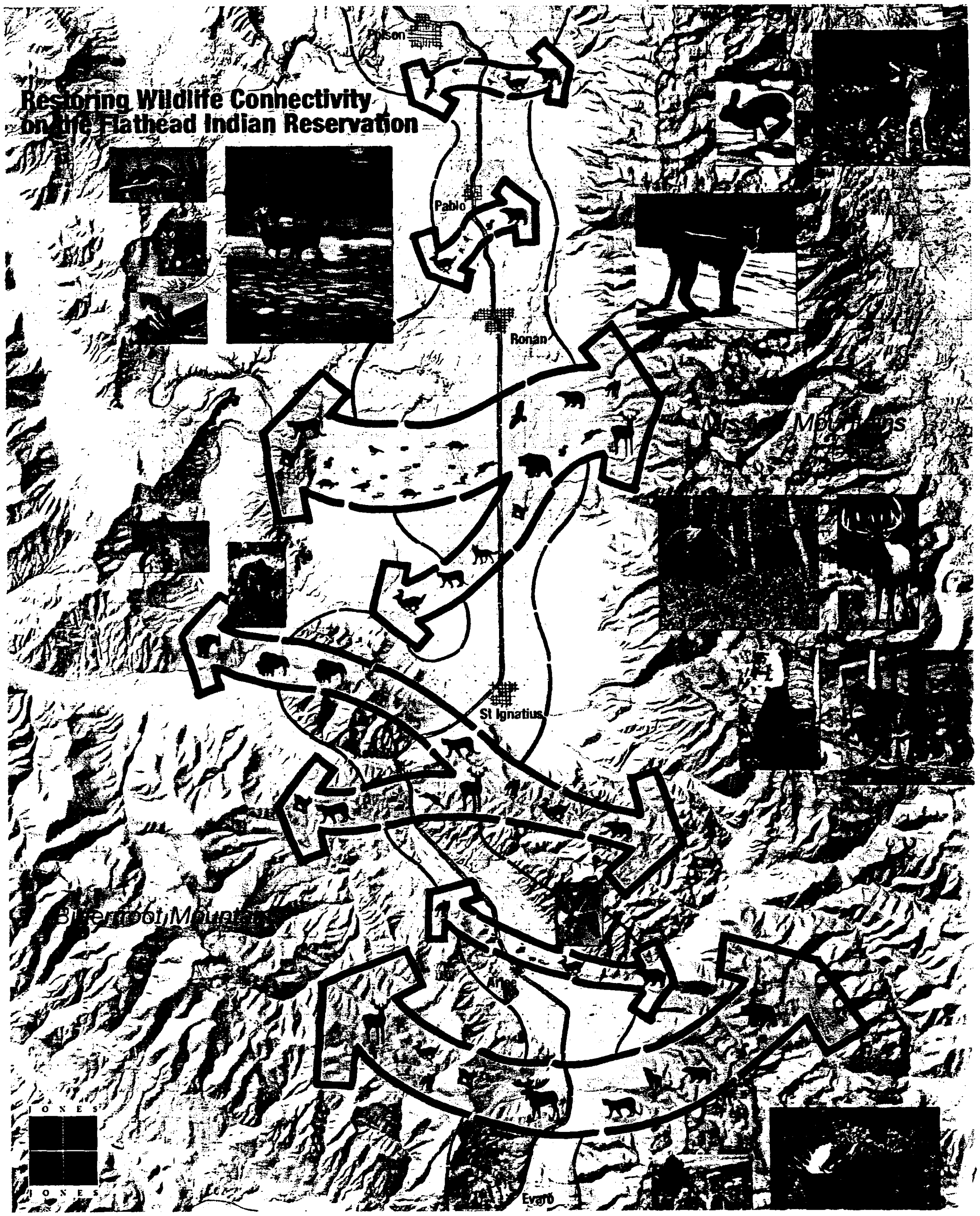



**Plate 12.** Restoring wildlife connectivity on the Flathead Indian Reservation across a major highway relies on local ecological knowledge. (*Concept graphic by Jones & Jones Architects and Landscape Architects*)

TABLE 11.2.

*Typical costs for restoration activities (in 2004 dollars). These are not absolute costs but can be used to produce a rough estimate of project costs.*

| Item | In-House Costs[a,b] | Contracted Costs[c] |
|---|---|---|
| Restoration planning | $25–50/hour | $90–120/hour |
| Site work, contouring to grade | | |
| With motorized equipment (e.g., front end loader) | NA | $22–35/hour |
| Hand labor | $10–22/hour | $15–25/hour |
| Reconstruction of soil bed | $10–22/hour | $15–25/hour |
| Soil (site-specific mix) | $50–75/cu. yard | $50–75/cu. yard |
| Nonnative plant control | $14–22/hour | $25–45/hour |
| Seed collection and cleaning | $10–15/hour | $30–45/hour |
| Hydroseeding and hydromulching | NA | $400–800/acre |
| Mulching and placement of erosion control matting | $10–22/hour | $1,000–2,000/acre |
| Erosion control matting | $116/roll, covers 720 s.f. | $116/roll, covers 720 s.f. |
| Plant propagation | | |
| 4-inch pot | $0.75–1.50/plant | $0.60–1.20/plant |
| 1 gallon | $2–5/plant | $3–7/plant |
| 5 gallon | $5–20/plant | $10–20/plant |
| 5-foot tree | $20–50/plant | $30–120/plant |
| Plant delivery and installation | | |
| 4-inch pot | $0.75–1.50/plant[d] | $0.75–2.00/plant |
| 1 gallon | $2–5/plant | $8–15/plant |
| 5 gallon | $15–40/plant | $30–50/plant |
| 5-foot tree | $25–50/plant | $75–150/plant |
| Postplanting plant care | $10–22/hour | $15–25/hour |
| Monitoring | $10–25/hour | $15–30/hour |
| Mobilization | NA | $500–3,000[e] |
| Per diem | NA | $50–100/day/person[f] |

[a]In-house costs are based on federal government pay scales and do not include administrative overhead because these costs ordinarily are not paid directly from project funds. Costs assume existing program with necessary infrastructure (greenhouse, certifications, training).

[b]Except for plant propagation, costs do not include volunteer time, which can significantly reduce the overall cost of a project.

[c]Contracted costs are based on quoted rates from several contractors and include administrative overhead. Contractor costs vary by region and expertise.

[d]Includes helicopter transport where necessary. Contracted costs do not include helicopter transport.

[e]Mobilization costs vary greatly depending on equipment needs and distance from the project.

[f]Per diem varies greatly depending on location and housing availability.

A cost estimate based on a per-plant or per-area basis should be based on a history of similar projects with good cost tracking. To determine the costs per plant or area at Mt. Rainier National Park, the total cost for restoration related to subalpine meadows for one season was calculated. This was divided by the number of plants produced and planted to provide an estimate of approximately $3 per plant for subalpine meadow restoration. This estimate includes seed collection; plant propagation and growth; transport of plants, materials, and personnel to the site, including some helicopter transport of plants and materials; topsoil meeting park standards; some gravel for site stabilization; erosion control matting; watering; equipment replacement; and limited success monitoring. Volunteer time, which is substantial, is not included in this cost estimate because the volunteer base is reliable year to year. For estimating costs of routine subalpine restoration projects with similar needs, this per-plant figure is used. With larger projects that involve contracting this figure is used for an initial estimate to determine initial funding allocations, but an itemized cost estimate is developed for the final project.

Itemized restoration cost estimating is most beneficial for projects that include a lot of site-specific earthwork, plants needing long growing and holding times in the nursery, and contracted work. In contracting, mobilization costs vary greatly depending on the location of the contractor, location of soil and gravel materials, and location of plant materials. Additionally, contractors generally receive per diem costs. Table 11.2 lists typical restoration activities and estimates of costs in 2004 for work by a contractor and work conducted with existing staff.

### Case Study: Restoration of a Small Impact: Paradise Social Trail

Paradise is a heavily used subalpine meadow in Mt. Rainier National Park. Each year approximately 2 million people visit Mt. Rainier, and most travel to Paradise to see the beautiful subalpine meadows that are easily accessed from the main park road. The Paradise Meadows extend from about the forest line at 5,400 feet (1,646 meters) up to the tree line at about 7,000 feet (2,134 meters) and encompass about 1,000 acres (416 hectares) of subalpine parkland. The area has been heavily used for more than 100 years, and by the mid-1980s, more than 900 social trails were documented in the Paradise area, in addition to the extensive, officially maintained trail system (Rochefort 1989). In 1986, Mt. Rainier National Park initiated a comprehensive program to document all impacts, upgrade the trail system, and restore unacceptable impacts to subalpine meadows. Because recreational use in the Paradise meadow was limited to day use along trails, most impacts were linear impacts or social trails. Social trails ranged from short trails with bare, compacted surfaces to long trails with erosion up to 3 feet (1 meter) deep. This case study presents the work conducted along one social trail in the Golden Gate area of Paradise.

#### Restoration Site and Goals

The Golden Gate trail climbs from about 6,000 feet (1,829 meters) to 7,000 feet (2,134 meters) through a heath–shrub–lush herbaceous meadow mosaic with about five switchbacks. This trail has been used since the early 1900s, and in this time sixteen shortcuts have developed in the lower part of the trail. We will present one of these switchbacks (GG12) as a typical example of restoration of a social trail. In 1986, the social trail was mapped and measured before initiation of restoration. At the time, the social trail was 116 feet (35.5 meters) long, 5.6 feet (1.7 meters) wide, and 1.2 feet (0.37 meter) deep. It extended between two sections of the switchbacked trail and was on a slope of 40% through a heath–shrub meadow. Dominant species in the area were mountain huckleberry (*Vaccinium deliciosum*) and red mountain heath, with lesser amounts of Cascades aster (*Aster ledophyllus*), alpine aster, western pasqueflower (*Anemone occidentalis*), sedges, and Cusick's speedwell (*Veronica cusickii*).

The goal for this area was to bring the trail up to the grade of adjacent areas, restore surface flow of water (it had become a channel for water draining from the trail), and restore the subalpine meadow. In 1986, the Mt. Rainier National Park greenhouse was not growing heather or huckle-

TABLE 11.3.

*Comparison of plant cover and species diversity on a restored social trail and the adjacent, undamaged meadow.*

| | Percentage Plant Cover | | | Number of Species | | |
|---|---|---|---|---|---|---|
| Site | 1993 | 1998 | 2005 | 1993 | 1998 | 2005 |
| Trail | 16 | 27 | 42 | 10 | 16 | 14 |
| Adjacent meadow | 82 | Unknown | 72 | 16 | Unknown | 20 |

berry species in large quantities, so it was decided that revegetation would make use of seeds and greenhouse plugs of less common species in the surrounding communities, including broadleaf lupine, sedges, cinquefoil, aster, luetkea, and pasqueflower in order to restore native plant cover and impede erosion.

## Restoration Methods

The first step in the process was to scarify the compact ground surface, then stabilize the site with subsurface erosion bars. Ninety wooden bars, 6 to 8 inches thick, were installed below the ground surface. After the bars were installed, 3 cubic yards of rock from an adjacent talus slope was placed on the scarified base, and the site was filled with a sterile soil mix (14 cubic yards). Finally, the site was planted, seeded, and covered with an excelsior mat to impede erosion and moderate soil surface temperatures and moistures. Planting and seeding continued over 3 years and involved 268 plants (ten species) and about 2 gallons of seeds (four species).

## Results

Today the site is well on its way to recovery, and bare slopes are less apparent than in 1986. Geomorphically, the site is at the grade of the adjacent meadow, and water flow seems to be dispersed across the surface; no channels are visible on the site. Vegetatively, the site is dominated by minor components of the adjacent heath–shrub meadow, but there is some evidence of vegetative spread of heather and huckleberry along edges of the impact (Table 11.3). However, there is also evidence of recent use (footprints) that indicates that restoration success may decrease if the site is not protected more aggressively. During the first few years of restoration, the site was roped off to discourage cross-country travel; however, over the last few years protection efforts have been less diligent, and footprints were visible in bare areas during our monitoring in 2004. Although plant establishment has been successful, high mortality of plants on several nearby restoration sites provides evidence that restoration success relies as much on protection as on revegetation.

### Case Study: Sunrise Campground, Mt. Rainier National Park

The Sunrise Campground was constructed in a subalpine meadow in Mt. Rainier National Park in the early 1930s. It was built in a valley adjacent to Yakima Park and Burroughs Mountain and provided beautiful views and easy hiking access to the subalpine parkland and alpine tundra. By the late 1960s, park managers realized that the beautiful setting of the campground was very sensitive to human use, and the popularity of the area was resulting in severe damage to natural resources (Figure 11.4). Curious campers, adventurous hikers, and vehicles wandered off the constructed roads and trails and caused numerous impacts and soil erosion in the valley adjacent to the campground. In 1973 the camp was closed to cars, and gradually camping was reduced to a small walk-in area. In the late 1970s some road surfaces were removed, but restoration funding was not available for large-scale rehabilitation. By 1980, plants were reestablishing only on cut-and-fill slopes along roads where soils were not compacted and seeds could germinate and survive. In 1996, Mt. Rainier National Park staff concluded that active restoration was the only way to restore the subalpine meadow ecosystem.

The campground is located on the east side of the park at about 6,400 feet (1,951 meters) elevation. A mosaic of tree clumps and herbaceous meadows characterizes vegetation of the area. Tree islands are dominated by subalpine fir, Engelmann spruce, and whitebark pine. The subalpine meadow is composed of green fescue, lupine, paintbrush (*Castilleja* spp.), and several asters. Vegetation in this area is sensitive to human use because of the short growing season and low resilience of plants to trampling. Typically the snow-free growing season extends for only 8–12 weeks in summer. Additionally, obscure Indian paintbrush (*Castilleja cryptantha*), an endemic plant, grows in wet meadows in the campground loops. This species is listed as sensitive on both the federal and

**Figure 11.4.** Sunrise Campground in 1931 illustrates intensity of recreation use beginning many decades ago. (*Photo by National Park Service*)

Washington State endangered species lists. It occurs only on twenty-five sites in Mt. Rainier National Park and two sites in the Wenatchee National Forest.

The former campground had four auto camp loops dispersed over about 50 acres. Restoration challenges included roadbeds, culverts, and sixty social trails. Although some natural revegetation had occurred over the preceding 25 years, it was limited to fill slopes along road edges. Based on the observed rate of plant succession on this site and other disturbed areas in the park's subalpine zone, park staff did not expect this area to revegetate naturally within the next 200 years. Even where plants had established naturally along the road corridor, the cut slope was still easily recognized by the altered topography and hydrologic patterns, resulting in different vegetation communities. In order to restore this site to subalpine parkland, it was necessary to restore the original land contours and hydrologic patterns, followed by revegetation of the disturbed areas. The plan included retention of a ten-site walk-in camp, with a new 1-mile access trail built in an existing roadbed.

In the 1980s, several restoration proposals were created, but it was not until 1996 that three partners came together to make the project feasible. In 1996, park personnel conducted surveys to quantify restoration needs and began meetings with the Washington National Guard 898th Engineer Battalion. Field surveys documented that 8,850 linear feet of roadway and approximately 10 acres of disturbed land would need to be treated. The Washington National Guard expressed an interest in using the road removal and recontouring as a training project as long as the park provided meals for the troops. Although personnel from Mt. Rainier National Park had previous experience in restoring small recreational impacts such as social trails and campsites (Rochefort and Gibbons 1992), complete restoration of large road surfaces had not been done. The park developed a funding proposal to the National Park Foundation. In January 1997, the foundation and the Canon Expedition into the Parks Program awarded a grant of $50,000. Work began immediately with strategic planning, development of interpretive materials, and initiation of restoration on the ground in July 1997.

## Goals and Objectives

The broad goals of this project were to reestablish the natural subalpine ecosystem, protect cultural resources, interpret the project for the public, and retain a small walk-in campground to facilitate overnight recreation. More specific objectives included restoring the original contours or landforms, recreating natural hydrology, and using native plant communities. Cultural components included stabilizing and preserving a historic building and conducting surveys for archeological sites or artifacts. Interpretation included creating a brochure and videotape documenting the project. Interpretation was an essential component to help ensure future protection of the restored landscape.

## Process

The process included planning, historic building stabilization, plant salvage, physical restoration, trail construction, revegetation, monitoring, and interpretation. Planning began in July 1996 concurrent with seed collection for future greenhouse propagation. In the fall and winter of 1996–1997,

plant propagation was initiated and planning completed, with compliance documents com
by May 1997. Adjustments to planning details occurred during implementation and annual re
Plants were salvaged from the cut-and-fill slopes and stored in temporary onsite beds in July
before road removal and recontouring. Once the roads were recontoured, the trail crew
building a 1-mile trail to the campground on a former roadbed. Once the physical restorati
complete, revegetation began.

## Methods of Physical Restoration

Physical treatments were designed to correct the effects of road-related disturbance and in
outsloping, decompaction and shaping, and road and stream crossing culvert excavati
removal. Supportive actions included scarifying, grading, or loading and transporting road s
materials to a specified fill site; loading and transporting portions of existing debris piles (lo
and rock); and transporting and stockpiling old water line and other utilities for off-site dispo
materials stored at fill site locations were buried under at least 2 feet of clean fill and appro
cover material.

Outsloping moved sidecast fill from the downslope edge of roads up against cutbanks (F
11.5a). All areas where fill was placed were decompacted, or ripped to a 2-foot depth first. T
ished surface was shaped to blend with the surrounding topography. Native topsoil was sto
and placed over the surface during final shaping.

Decompaction was also used on flat areas, such as road surfaces. Many of the road surfac
originally covered with oiled gravel, 750 cubic yards of which were removed and used elsew
fill. Gravel and soil were tested to ensure that no contaminants were present. A sufficient num
passes were made to attain a maximum spacing of 2 feet between adjacent ripper shank pat
decompacted surface was then reshaped, where necessary, to blend with the surrounding to
phy.

Road and stream crossing excavations involved the removal and disposal of fill, sewer c
and other debris from five stream channels, followed by shaping of the completed excava
blend with the surrounding land (Figure 11.5b). In most cases, the finished product close
icked the original (pre–road construction) stream channel and side bank configuration. All
stored in local areas (outsloped) or used as cover material at fill sites.

Work on all treatments was closely supervised to detect changes in the character of su
materials, with adjustments to specifications of the treatment to maximize physical treatmen
tiveness. Identified native topsoils were selectively handled to ensure that they were placed
surface during final shaping.

## Revegetation

We developed our revegetation strategies by first examining the plant communities and la
in the project area, identifying reference communities for each section of the disturbed ar
of the cut-and-fill slopes were naturally recovering and were partially covered with native
lupine communities or had early successional species such as Newberry's fleeceflower (Poly

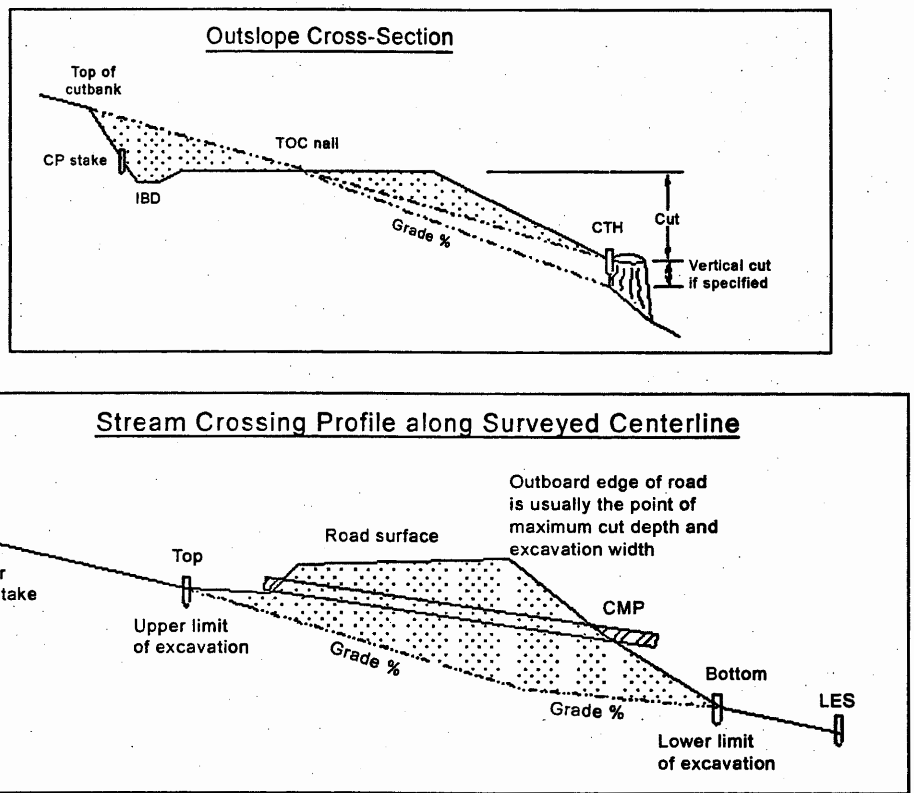



FIGURE 11.5. *(a)* Cross-section showing a typical outslope trail design. *(b)* Profile (along centerline) showing typical road and stream crossing treatment.

*newberryi*), *Aster ledophyllous*, or *Veronica cusickii*. A decision was made to supplementally seed these sites to assist natural reestablishment on these slopes. Much of the original road surface was on areas with a slight slope that historically would have been covered with one of three plant communities: dry grass (fescue)–lupine, heath–shrub, or low herbaceous (sedges and rushes). Despite decompaction and reshaping, we believed the soil was more compact than on the cut-and-fill slopes and active planting and seeding were needed. We started closest to the new trail that led to the walk-in campground because this area had the highest risk of being trampled. Depending on the micro-topography, these areas were planted with the dry grass or low herbaceous community. Heath–shrub communities were in areas farther from visitor use and were planted because of their very slow natural recruitment. Revegetation on these areas was delayed until after the areas closest to visitor access were completed.

After the contouring was complete, we collected soil samples in the three plant communities (dry grass, heath–shrub, and low herbaceous) to determine what was in the seedbank. We found only seven species at very low densities. *Juncus* species were found in all plant communities and at the highest volume. Other species were uncommon and included showy sedge, green fescue, fireweed

(*Epilobium* spp.), fanleaf cinquefoil, and two unknowns. This analysis confirmed that we would need to rely on plant propagation and direct seeding to establish cover within the first few years. Over the course of this project, propagation has included a total of seventeen species, although only seven to thirteen species have been propagated in any one year. The volume of plant materials collected depends on the community being restored, seed availability, and greenhouse staffing (volunteers or paid employees). Plants are seeded and planted in September, before the fall rains or snow. Showy and black sedge, green fescue, fleabane (*Erigeron peregrinus*), cinquefoil, wooly everlasting (*Antennaria lanata*), and alpine aster have been the most common species propagated (Table 11.4).

## Monitoring Results

Surveys indicated that initial survival of planted material exceeded 90%, but there was uncertainty with regard to whether function was being restored. In order to quantitatively evaluate restoration of function and structure, we recruited a graduate student, Kim Frappier, from the University of Washington, who conducted her master's thesis on the site.

Frappier's study examined plant community and soil characteristics in the restoration area and compared them with nearby undisturbed subalpine meadows. Qualitative and quantitative monitoring is considered an integral component of the restoration program at Mt. Rainier National Park. However, only qualitative assessments of the Sunrise restoration had been conducted, focused on seeding success, seedling survival, and mulch condition. The objective of Frappier's study was to evaluate the Sunrise restoration ecologically through a quantitative approach by comparing soil chemical, physical, and biological properties between restoration sites of different ages, comparing vegetative cover and species composition in the restoration sites and adjacent undisturbed meadows, and evaluating the productivity of greenhouse-grown green fescue plugs in restoration sites.

## Study Methods

Portions of road corridor were revegetated each year between 1997 and 2001, resulting in six separate sections. A chronosequence based on the time since planting was used to analyze changes in plant and soil properties over time. A similar approach was used by Fyles et al. (1985) in their study of vegetation and soil development on coal mine spoil in the Canadian Rockies. In a chronosequence, sites of different ages are assumed to represent points in time in the development of an individual site. Because a longitudinal study was not possible, the chronosequence allows a space-for-time substitution.

In the summer of 2002, 100 sampling points in the restoration area and 30 sampling points in the reference area were established using a simple random sampling method. Total percentage cover and cover of individual species were collected using a variation of the cover class system outlined by Elzinga et al. (1998). Aboveground biomass of green fescue was estimated using regression analysis. This reduced the number of plants harvested from the restoration site.

TABLE 11.4.

*Plant materials and labor used to restore Sunrise Campground.*

| Year | Number of Plants | Volume of Seeds (mixed species) | Paid Work Hours[a] | Volunteer Hours[a] |
|---|---|---|---|---|
| 1997 | 17,112 | 119 cups (1,342 square feet) | 2,216 | 2,269 |
| 1998 | 28,290 (5,383 square feet) | 133 cups (1,967 square feet) | 959 | 1,579 |
| 1999 | 27,077 | 11 cups (100 square feet) | 1,439 | 931 |
| 2000 | 41,076 | 235 cups (3,587 square feet) | 2,200 | 977 |
| 2001 | 21,582 (16,504 square feet) | 114 cups (928 square feet) | 2,097 | 952 |
| 2002 | 16,002 (4,825 square feet) | 47 cups (786 square feet) | 713 | 603 |
| 2003 | 12,219 (3,542 square feet) | 100.5 cups (1,251 square feet) | 1,520 | 2,911 |
| 2004 | 26,403 (5,705 square feet) | 4 cups (44 square feet) | 721 | 735 |

[a]Hours do not include greenhouse propagation, which ranged from 1,280 hours in 1997 to 2,480 hours in 2004.

Soil samples were collected in August and September 2002 from selected planted, unplanted, and reference sites. All samples were collected from the top 15 centimeters of the soil surface using a trowel and bulb planter. Samples were taken from the rooting zone of plant clumps. In cases where there was no vegetation, soil was collected to the same depth (15 centimeters) as samples beneath plants and included in analysis. Analysis conducted on these samples included soil moisture, carbon/nitrogen ratio, percentage carbon and nitrogen, microbial biomass and activity, pH, and available nitrogen.

## Research Results

Analysis showed an overall increase in plant cover as the age of the planted site increased. There was an 18% increase in plant cover from the 2-year-old site to the 6-year-old site. Only a 5% difference was observed in cover between the 6-year-old restoration site and the reference site, indicating that plant cover target conditions had nearly been achieved. Ordination analysis confirmed the linear relationship between the age of the restoration site and plant cover. Despite the progress in plant cover, the 6-year-old site lacked the species diversity of the reference sites and continued to look like a planted landscape, as opposed to a natural one. Overall, a greater number of species was found on reference sites (twenty-six species) than on the five replanted sections, which had an average of twelve species. Green fescue cover and biomass in grams per square meter increased as the age of the restoration site increased. Green fescue cover was zero on the unplanted site, reflecting a lack of natural recruitment. The vegetation survey did not produce evidence of natural recruitment into revegetated sites except for two species: Newberry fleeceflower (*Polygonum newberryi*) and subalpine fir. These were the only two natural recruiters found on the unplanted site as well. This has important implications for restoration strategies, particularly when the restoration objective is to restore species composition and cover as quickly as possible.

Soil variables showed wide variation. Overall, carbon/nitrogen ratios, soil pH, and microbial biomass were similar across both reference and revegetated sites. The largest difference in carbon/nitrogen ratios was found between the unplanted restoration section (14 ± 0.87) and the reference sites (17 ± 1.62). Increases were observed for the total percentage of carbon in restoration sites (1.9% to 2.6%) and between unplanted (1.6%) and reference sites (3.9%). Soil moisture increased from the unplanted site (8.2%) to the 6-year-old site (13%). However, this pattern did not hold true on the reference sites, which equaled that found on the unplanted site. Available and total nitrogen were lowest in the unplanted site (net = 0.0013 mg/g, total = 1.13 mg/g), compared with the 6-year-old site (net = 0.0023 mg/g, total = 1.56 mg/g), and highest in the reference sites (net = 0.0043 mg/g, total = 2.25 mg/g).

The sparse cover on the unplanted restoration site and the low percentage of carbon and low levels of total and available nitrogen confirmed that revegetation efforts speed the recovery of disturbed subalpine plant communities, not simply in terms of vegetation cover but in terms of soil processes as well. Overall, results confirm that the restoration sites at Sunrise are on a trajectory toward recovery (Figure 11.6). The increase in vegetation cover and green fescue biomass, coupled with the increase in percentage of carbon, soil moisture, and total and available nitrogen on revegetated sites, reflects continued growth of greenhouse plants, litter accumulation, and the increase in soil nutrients.

## Future Research and Restoration

To elucidate the viability of the plant community on the Sunrise restoration, a long-term demographic monitoring project similar to those conducted by Urbanska (1994) on restoration plots in the Swiss Alps would be useful. Demographic monitoring examines the age-state structure of plants, including flower and seed production. This, coupled with further soil analysis, would assist in analysis of the sustainability and trajectory of the restoration sites.

In the harsh subalpine ecosystem, survival and continued growth of greenhouse-grown plants are an important first step to restoration success. We plan to continue revegetation of the site with greenhouse plants and direct seeding for at least the next decade. We also plan to continue to monitor the site to assess plant cover and soil ecological processes, refine current revegetation prescriptions, and evaluate the trajectory and success of the Sunrise restoration. See Plate 7 in the color insert for more subalpine restoration examples.

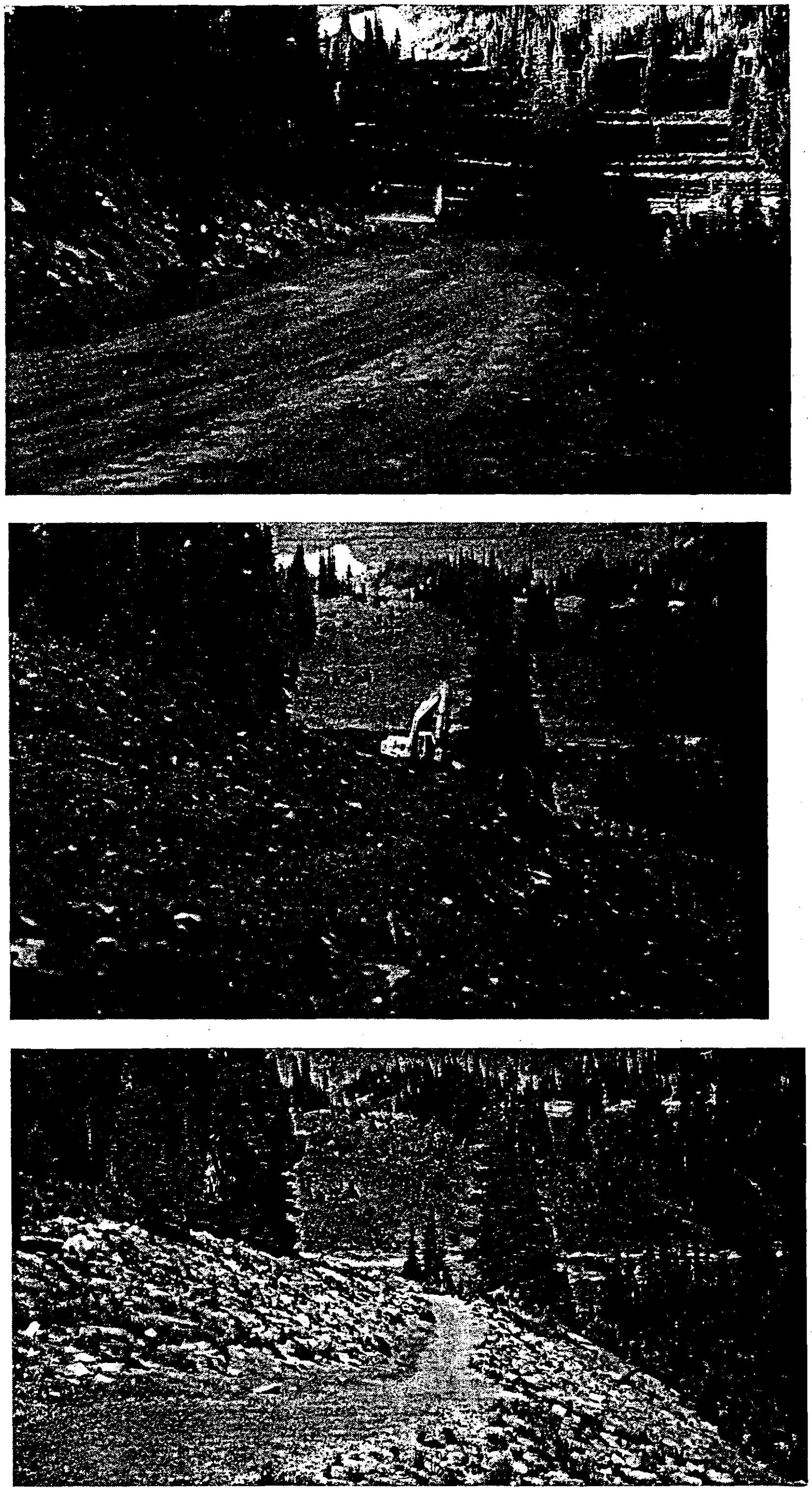


**Figure 11.6.** Road at Sunrise area *(top)* before, *(middle)* during, and *(bottom)* after restoration and conversion to a trail. (*National Park Service*)

### Case Study: Whitebark Pine Restoration in Glacier National Park

Glacier National Park is situated in an area known as the Crown of the Continent. It is the meeting ground for four floristic provinces (Cordilleran, Boreal, Arctic-Alpine, and Great Plains) and is known for having all of its native predators intact. Unfortunately, three of these predators, the grizzly bear (*Ursus arctos horribilis*), gray wolf (*Canis lupus*), and Canada lynx (*Lynx canadensis*), are federally listed as threatened. A critical resource for the grizzly bear, the whitebark pine ecosystem is seriously threatened in the park.

Historically, whitebark pine communities were significant components on 15–20% of forested lands in Glacier National Park, occurring on 75,000–100,000 acres. Whitebark pine is considered a keystone species because a wide variety of wildlife depend on the high-fat seeds for food, including not only the grizzly bear but also red squirrels (*Tamiasciurus hudsonicus*), Clark's nutcracker (*Nucifraga columbiana*), and many others. The pines influence vegetation patterns across the landscape by pioneering dry, cold, exposed sites where no other tree species can establish. Their penchant for growing on windy ridges allows them to accumulate and retain snow, thus lengthening the snowmelt period. They also contribute high aesthetic value as their unique growth form characterizes the subalpine landscape. Whitebark pine stands also are important aspects of cultural and spiritual importance to neighboring tribal members.

Fire exclusion has hampered regeneration, and an exotic fungus, white pine blister rust (*Cronartium ribicola*), has decimated whitebark pine stands in Glacier National Park. Nearly half of all the trees have died. Of the remaining live trees, more than 75% are lethally infected and probably will die within a few decades (Figure 11.7). A quarter of the cone-bearing crowns on these trees have already died (Kendall and Keane 2001). White pine blister rust is a widespread problem in the Northwest and continues to spread. Stands surveyed in Washington, northern Idaho, northwest Montana, southern Alberta, and British Columbia were found to have 50–100% infection rates in live trees, with 40–100% of trees in each stand already dead (Kendall and Keane 2001).

A thorough inventory of whitebark pine in Glacier National Park was conducted in 1995–1997, resulting in a digitized map of stands and documented mortality rates and causes (Kendall et al. 1996). Based on these data, scientists and park managers agreed that whitebark pine will be functionally lost in the absence of active intervention. As a result, a whitebark pine and limber pine (*Pinus flexilis*, also affected by blister rust) restoration program was initiated in 1998. This case study focuses only on the whitebark pine.

## Objectives

The primary goal was to maintain whitebark pine populations by planting seedlings that show genetic resistance to blister rust. Project components include the following:

- Forging cooperative agreements with neighboring agencies
- Conducting surveys to identify healthy trees in blister rust–decimated stands and collecting seeds from them
- Developing propagation protocols, using seed to grow seedlings

FIGURE 11.7. Whitebark pine dying among subalpine fir in Preston Park. *(National Park Service photo)*

- Identifying and selecting appropriate habitats to plant trees
- Monitoring to determine successes, failures, and needed improvements

## Methods

In spring and early summer, trail crews and other field personnel were recruited to keep watch for and report locations of cone-producing trees. Primary collection sites identified included Preston Park, Oldman Lake, Bighorn Basin, and Siyeh Bend, all areas that had been hard hit by white pine blister rust. Pending genetic rust resistance studies being conducted by the U.S. Forest Service research station in Moscow, Idaho, the accepted approach is to assume that healthy cone-producing trees in these stands are likely to have some degree of natural rust resistance (Hoff et al. 2001).

In mid to late July, quarter-inch wire mesh cages were packed into the backcountry, trees climbed, and cones caged. Field technicians were trained in tree-climbing methods and used ropes and harnesses for safety. A contracted tree climber was also employed. In a few instances, cages broke or were blown off, but most stayed secure. Upon return in late September to collect cones, no seeds were found outside cages. They had all apparently been harvested by Clark's nutcrackers and red squirrels. In some areas animals had gotten inside the cages and raided the cones, highlighting the need for secure fastening.

Most seed was sent to the Forest Service's Coeur d'Alene Nursery to be raised as seedlings; a small percentage was kept to be raised in the park nursery along with cooperators in greenhouses at the Columbia Falls High School and the Blackfeet Community College. Because of its excellent facilities, the Coeur d'Alene Nursery was able to produce better stock than the park could on site. (Specific propagation protocols for whitebark pine can be obtained from the Coeur d'Alene Nursery.) If requests are submitted by the fall before sowing, the stock can be ready for planting within a year and a half after germination. In addition, resources were shared with the Waterton Lakes National Park across the border in Canada, where direct seeding field trials had been initiated recently.

Recent burn perimeters were overlain with a geographic information system layer of potential and existing whitebark pine habitat to aid selection of planting locations (Peterson 1999). Recent natural fires that burned through existing whitebark pine stands provide ideal planting conditions. Remaining black islands were selected for planting, and trees were placed near stumps or snags for shading. The trees were watered with a diluted B1 transplant solution and mulched with nearby light-colored duff. Trees targeted for future monitoring were planted and mapped in a series of circular plots, at various distances and compass bearings from a central point recorded using a global positioning system. Monitoring plots were installed to track about 15% of the planted trees.

In July 2001, 1,500 trees were planted on West Flattop Mountain in the 1998 Kootenai Complex burn area, and more than 1,400 were planted the next September with the help of Montana Conservation Corps volunteers. Because of the unpredictability of summer moisture, all subsequent plantings have been carried out in September. More than 2,000 additional whitebark were planted in the same area in 2002. In a couple of instances, groups of about 100 trees were flown to sites immediately after fires during resource monitoring. There has not been an opportunity to monitor survival at these sites because of their remote locations. In addition, more than 600 trees were shared cooperatively with the Blackfeet Indians, as students planted them on the reservation.

## Results

Between 1997 and 2001, more than 22,500 whitebark pine seeds were collected. Germination results varied each year. The biggest cone crop was in 1998, with the percentage of fill ranging from 72% to 96%. In 1998, the seed averaged 67% germination (with individual tree lots as high as 8[illegible]). In contrast, in 1999 whitebark cones were very late in maturing, most of the seed molded in stratification, and there was almost no germination. It is likely that the seed never fully matured that year. It was encouraging to discover that 86% germination could be obtained from a lot of two-and-a-half-year-old seed. At least 75% of the germinants reached seedling stage.

## Seedling Survival

Seedlings can be overwintered if they cannot be planted during the summer they are delivered, but overwintering is risky. High mortality was experienced in overwintered stock as a result of rodent predation and possible overheating of the conifers under protective foam and plastic used to cover stock. Use of rodenticides and discontinued use of white plastic cover has been successful in reducing overwinter mortality. Seedlings should not be held over for more than 1 year without repotting.

Seedlings planted in July 2001 were monitored for survival in September. There was a rainstorm shortly after the trees were planted, but the remainder of the summer was extremely dry. About one third succumbed to drought, a surprisingly good result considering the lack of precipitation in the preceding 2 months. The 2001 spring and fall plantings were surveyed in 2002 and showed a 45% survival rate after the first year. Trees were not surveyed in 2003–2004, but year 4 survival will be monitored in 2005.

## Budget

From 1998 to 2003, more than 6,000 whitebark pine trees were planted. Although thousands of seeds can be collected during a good cone crop year, it was necessary to stagger the sowing of the seeds so as not to produce more material than could be handled for outplanting in one season. Approximately one third more seed was sown than the target for seedling production.

The overall costs were nearly $6 per tree planted. One third was in propagation, one sixth in planting, another sixth in transportation, and the rest in various categories. The cost of planning logistics, scouting, caging cones, collecting seed, processing cones, establishing monitoring plots, monitoring results, entering related data, and preparing summary reports added another $2 per tree. This does not include project supervision and oversight or preparation of funding proposals. Costs can vary, but these figures may provide a rough guide to others considering similar projects. Because most federal funding comes in 2- to 3-year blocks, the project was separated into phases, first for development of seed collection and propagation strategies and next for development of planting and overall restoration strategies.

## Conclusions

Objectives were met through cooperative efforts between the Park Service, the U.S. Forest Service, the Blackfeet Tribe, and Waterton Lakes National Park. All worked together to achieve the common restoration goal for whitebark pine ecosystems. A number of healthy, cone-producing trees (sometimes called "plus" trees) have been located in heavily hit blister rust stands. Successful seed collection and propagation methods were pioneered on this project that can now be used elsewhere.

Fall planting, timed shortly before seasonal moisture arrives, is more successful than spring planting, when summer precipitation cannot be predicted. Fall moisture is more reliable. The young trees go into dormancy shortly after planting, then take advantage of spring moisture to give them a boost for the next season. Microsite planting is extremely important. The seedlings must have some shade, whether it is from a stump, a rock, or a snag, or they are likely to succumb to desiccation. Recently burned areas were ideal as planting locations. We continue to research additional criteria for selection of additional planting locations.

Monitoring is important for learning what strategies do or do not work well and determining the ultimate success of the program (Figure 11.8). Drought is a great inhibitor of survival, and the ideal time to complete restoration would be during a wetter cycle, which unfortunately is very difficult to predict when one is requesting funding for multiyear projects. Supplemental watering would be helpful but is not feasible in remote and widely scattered planting locations.

We have concluded that an active restoration program is critical for the long-term survival of whitebark pine in Glacier National Park. With modifications based on lessons learned, we hope that a long-term restoration program for whitebark pine will be established.

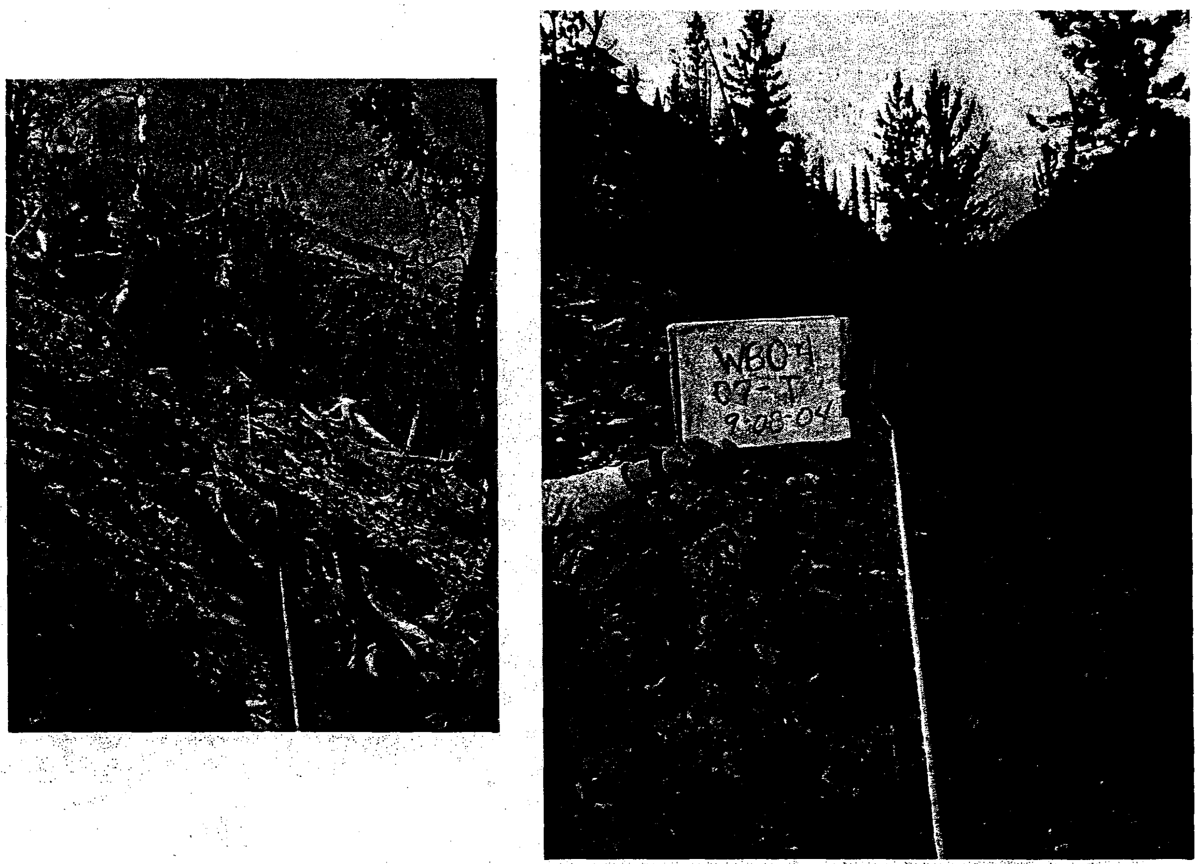



FIGURE 11.8. *Left*, Whitebark pine blister rust survey transect near Red Gap Pass trail, Glacier National Park. *Right*, Whitebark pine blister rust survey transect southeast of Numa Lookout, Glacier National Park. (*National Park Service photos*)

REFERENCES

Agee, J. K. and L. Smith. 1984. Subalpine tree establishment after fire in the Olympic Mountains, Washington. *Ecology* 65(3): 810–819.

Bergland, E. O. 1984. *Olympic National Park Archeological Basemap Study: Summary Report to Superintendent Chandler*. Division of Cultural Resources, Pacific Northwest Region, National Park Service, Seattle.

Billings, W. D. 1973. Arctic and alpine vegetations: similarities, differences, and susceptibility to disturbances. *BioScience* 23(12): 697–704.

Billings, W. D. and L. C. Bliss. 1959. An alpine snowbank environment and its effect on vegetation, plant development, and productivity. *Ecology* 40: 388–397.

Billings, W. D. and H. A. Mooney. 1968. The ecology of arctic and alpine plants. *Biological Reviews* 43: 481–529.

Brink, V. C. 1959. A directional change in the subalpine forest–heath ecotone in Garibaldi Park, British Columbia. *Ecology* 40(1): 10–16.

Buol, S. L., F. D. Hole, and R. J. McCracken. 1980. *Soil Genesis and Classification*. Iowa State University Press, Ames.

Burtchard, G. C. 1998. *Environment, Prehistory & Archaeology of Mount Rainier National Park, Washington*. Unpublished report prepared for U.S. Department of Interior, National Park Service, Mt. Rainier National Park, and International Archaeological Research Institute.

Campbell, E. M. and J. A. Antos. 2000. Distribution and severity of white pine blister rust and mountain pine beetle on whitebark pine in British Columbia. *Canadian Journal of Forest Research* 30: 1051–1059.

Campbell, P. R. 1996. *Population Projections for States by Age, Sex, Race, and Hispanic Origin: 1995 to 2025*. PPL-47. Population Projections Branch, Population Division, U.S. Bureau of the Census, Washington, DC.

Canaday, B. B. and R. W. Fonda. 1974. The influence of subalpine snowbanks on vegetation pattern, production, and phenology. *Bulletin of the Torrey Botanical Club* 101: 340–350.

Catton, T. 1996. *Wonderland: An Administrative History of Mount Rainier National Park*. National Park Service, Seattle.

Choquette, W. T. 1981. The role of lithic raw material studies in Kootenay archaeology. *BC Studies* 48: 21–36.

Clague, J. J. and R. W. Mathewes. 1989. Early Holocene thermal maximum in western North America: new evidence from Castle Peak, British Columbia. *Geology* 17: 277–280.

Clague, J. J., R. W. Mathewes, W. M. Buhay, and T. R. Edwards. 1992. Early Holocene climate at Castle Peak, south Coast Mountains, British Columbia, Canada. *Palaeogeography, Palaeoclimatology, Palaeoecology* 95: 153–167.

Douglas, G. W. 1970. *A Vegetation Study in the Subalpine Zone of the Western North Cascades, Washington*. M.S. thesis, University of Washington, Seattle.

Douglas, G. W. and L. C. Bliss. 1977. Alpine and high subalpine plant communities of the north Cascades region, Washington and British Columbia. *Ecological Monographs* 47(2): 113–150.

Dunwiddie, P. W. 1977. Recent tree invasion of subalpine meadows by trees in the Wind River Mountains, Wyoming. *Arctic and Alpine Research* 9: 393–399.

Ecological Stratification Working Group. 1996. *A National Ecological Framework for Canada*. Agriculture and Agri-Food Canada, Research Branch, Centre for Land and Biological Resources Research and Environment Canada, State of Environment Directorate, Ottawa. Available at www.ec.gc.ca/soer-ree/English/Framework/framework.cfm.

Edwards, O. M. 1980. *The Alpine Vegetation of Mount Rainier National Park: Structure, Development, and Constraints*. Ph.D. dissertation, University of Washington, Seattle.

Elzinga, C. L., D. W. Salzer, and J. W. Willoughby. 1998. *Measuring & Monitoring Plant Populations*. BLM Technical Reference 1730-1.

Eng, M. 2003. *Large Scale Biogeoclimatic Mapping*. Available at www.for.gov.bc.ca/hre/becweb/subsite-map/largescale-01.htm.

Expert Committee on Soil Survey. 1987. *The Canadian System of Soil Classification*. 2nd ed. Agriculture Canada Publication 1646, Ottawa.

Franck, I. C. 2000. *An Archaeological Investigation of the Galene Lakes Area in the Skagit Range of the North Cascade Mountains, Skagit Valley Park, British Columbia*. Unpublished manuscript, Department of Archaeology, Simon Fraser University, Burnaby, BC.

Franck, I. C. 2003. *In the Shadow of Hozameen: An Archaeological Inventory of the Skyline Trail System in Manning and Skagit Valley Provincial Parks, Southwest B.C., Project Year Number One (2002)*. Prepared for Skagit Environmental Endowment Commission.

Franklin, J. F. and C. T. Dyrness. 1987. *Natural Vegetation of Oregon and Washington*. Oregon State University Press, Corvallis.

Fulkerson, C. 1988. *Predictive Locational Modeling of Aboriginal Sites in the Methow River Area, North-Central Washington*. Report submitted to the Okanogan National Forest, Purchase Order No. 00-05H7-7-2 10, Okanogan, WA.

Fyles, J. W., I. H. Fyles, and M. A. H. Bell. 1985. Vegetation and soil development on reclaimed mine land at high elevation in the Canadian Rockies. *Journal of Applied Ecology* 22(1): 239–248.

Galbraith, W. A. and E. W. Anderson. 1971. Grazing history of the Northwest. *Journal of Range Management* 24(1): 6–12.

Gavin, D. G. and L. B. Brubaker. 1999. A 6,000-year soil pollen record of subalpine meadow vegetation in the Olympic Mountains, Washington, USA. *Journal of Ecology* 87: 106–122.

Gehring, J. L. and Y. B. Linhart. 1992. Population structure and genetic differentiation in native and introduced populations of *Deschampsia caespitosa* (Poaceae) in the Colorado Alpine. *American Journal of Botany* 79(12): 1337–1343.

Goheen, E. M., D. J. Goheen, K. Marshall, R. S. Danchok, J. A. Petrick, and D. E. White. 2002. *The Status of Whitebark Pine along the Pacific Crest National Scenic Trail on the Umpqua National Forest.* Gen. Tech. Rep. PNW-GTR-530. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR.

Hamann, M. J. 1972. *Vegetation of Alpine and Subalpine Meadows of Mount Rainier National Park, Washington.* M.S. thesis, Washington State University, Seattle.

Henderson, J. A. 1974. *Composition, Distribution and Succession of Subalpine Meadows in Mount Rainier National Park.* Ph.D. dissertation, Oregon State University, Corvallis.

Hoff, R. J. 1992. *How to Recognize Blister Rust Infection on Whitebark Pine.* Research Note INT-406. USDA Forest Service, Intermountain Research Station, Ogden, UT.

Hoff, R. J., D. E. Ferguson, G. I. McDonald, and R. E. Keane. 2001. Strategies for managing whitebark pine in the presence of white pine blister rust. Pages 346–366 in D. F. Tomback, S. F. Arno, and R. E. Keane (eds.), *Whitebark Pine Communities: Ecology and Restoration.* Island Press, Washington, DC.

Ingersoll, C. A. 1991. *Plant Reproductive Ecology and Community Structure along a Subalpine Snowmelt Gradient.* Ph.D. dissertation, Oregon State University, Corvallis.

Juelson, J. L. 2001. *Restoring Subalpine Vegetation in the Enchantment Lakes Basin: Evaluating Restoration Treatments on the Seedling Emergence of* Juncus parryi, Carex nigricans, *and* Luetkea pectinata. M.S. thesis, Central Washington University, Ellensburg.

Kagan, J. and S. Caicco. 1992. *Manual of Actual Oregon Vegetation.* Available at www.gis.state.or.us/data/metadata/k250/GAPveg_250.pdf.

Keane, R. E. and S. F. Arno. 1993. Rapid decline of whitebark pine in western Montana: evidence from 20-year remeasurements. *Western Journal of Forestry* 8(2): 44–47.

Kendall, K. C. and R. C. Keane. 2001. Whitebark pine decline: infection, mortality, and population trends. Pages 221–242 in D. F. Tomback, S. F. Arno, and R. E. Keane (eds.), *Whitebark Pine Communities: Ecology and Restoration.* Island Press, Washington, DC.

Kendall, K. C., D. Schirokauer, E. Shanahan, R. Watt, D. Reinhart, R. Renkin, S. Cain, and G. Green. 1996. Whitebark pine health in northern Rockies national park ecosystems: a preliminary report. U.S. Forest Service Intermountain Research Station, Missoula, MT. *Nutcracker Notes* 7:16.

Lester, L. W. 1989. *Revegetation Efforts at North Cascades National Park Service Complex.* Presented at the Society of Ecological Restoration Management Annual Meeting, "Restoration: The New Management Challenge," January 16–20, Oakland, CA.

Linhart, Y. B. and J. L. Gehring. 2003. Genetic variability and its ecological implications in the clonal plant *Carex scopulorum* Holm. in Colorado tundra. *Arctic, Antarctic, and Alpine Research* 35(4): 421–433.

Linhart, Y. B. and C. A. Wise. 1997. *Genetic Variability in Populations of Revegetation Candidate Plants at Mt. Rainier National Park.* Unpublished report, EPO Biology Department, University of Colorado, Boulder.

Little, R. L., D. L. Peterson, and L. L. Conquest. 1994. Regeneration of subalpine fir (*Abies lasiocarpa*) following fire: effects of climate and other factors. *Canadian Journal of Forest Research* 24: 934–944.

McClure, R. H. Jr. 1989. Alpine obsidian procurement in the southern Washington Cascades. *Archaeology in Washington* 1: 59–69.

McNab, W. H. and P. E. Avers. 1994. *Ecological Subregions of the United States: Section Descriptions.* U.S. Department of Agriculture, U.S. Government Printing Office, Washington, DC.

Mierendorf, R. R. 1999. Precontact use of tundra zones of the northern Cascades range of Washington and British Columbia. *Archaeology in Washington* VII: 3–23.

Mierendorf, R. R. 2004. *Archeology of the Little Beaver Watershed, North Cascades National Park Service Complex, Whatcom County, Washington.* Report submitted to the Skagit Environmental Endowment Commission in fulfillment of Grant 02-01 by the National Park Service, North Cascades National Park Service Complex, Sedro-Woolley, Washington.

Moritsch, B. J. and P. S. Muir. 1993. Subalpine revegetation in Yosemite National Park, California: changes in vegetation after three years. *Natural Areas Journal* 13(3): 155–163.

Murray, M. P. and M. C. Rasmussen. 2003. Non-native blister rust disease on whitebark pine at Crater Lake National Park. *Northwest Science* 77(1): 87–91.

Nickels, A. M. 2002. *History under Fire: Understanding Human Fire Modification of the Landscapes of Mount Rainier National Park.* M.S. thesis, Central Washington University, Ellensburg.

Oregon Department of Forestry. 2003. *Land Ownership.* Available at www.gis.state.or.us/data/metadata/k24/public_ownership_draft.pdf.

Peterson, K. T. 1999. *Whitebark Pine (*Pinus albicaulis*) Decline and Restoration in Glacier National Park.* M.S. thesis. University of North Dakota, Grand Forks.

Pokotylo, D. L. and P. D. Froese. 1983. Archaeological evidence for prehistoric root gathering on the southern interior plateau of British Columbia: a case study from Upper Hat Creek Valley. *Canadian Journal of Archaeology* 7(2): 127–157.

Price, L. W. 1981. *Mountains and Man.* University of California Press, Berkeley.

Ramsay, M. J. 2004. *The Effects of Soil Amendment and Watering Regime on Germination and Establishment of Direct-Seeded Native Plant Species Used in Subalpine Restoration at Cascade Pass, North Cascades National Park.* M.S. thesis, University of Washington, Seattle.

Reeves, B. O. K. 2003. *Mistakis: The Archeology of Waterton–Glacier International Peace Park.* Vols. I and II. Submitted to the National Park Service, Intermountain Region, in fulfillment of Contract 290847, between Montana State University and the National Park Service, Bozeman.

Reimer, R. 2000. *Extreme Archaeology: The Results of Investigations at High Elevation Regions in the Northwest.* Unpublished MA thesis, Department of Archaeology, Simon Fraser University, Burnaby, BC.

Reimer, R. 2003. Alpine archaeology and oral traditions of the Squamish. In R. L. Carlson (ed.), *Archaeology of Coastal British Columbia: Essays in Honour of Professor Philip M. Hobler.* Publication No. 30, Archaeology Press, Simon Fraser University, BC.

Ripple, W. J. 1989. *Soil Textures for Selected Areas of Mount Rainier National Park.* Unpublished report, Oregon State University, Corvallis.

Rochefort, R. M. 1989. *Paradise Meadow Plan.* Unpublished report, Mount Rainier National Park, Ashford, WA.

Rochefort, R. M. 1990. *Mount Rainier National Park Revegetation Handbook.* Unpublished report, Mount Rainier National Park, Ashford, WA.

Rochefort, R. M. and J-Y. P. Courbois. In prep. *Status of Whitebark Pine in North Cascades and Mount Rainier National Parks, Washington.*

Rochefort, R. and S. Gibbons. 1992. Mending the meadow. *Restoration and Management Notes* 10: 120–126.

Rochefort, R. M., R. L. Little, A. Woodward, and D. L. Peterson. 1994. Changes in sub-alpine tree distribution in western North America: a review of climatic and other causal factors. *The Holocene* 4(1): 89–100.

Rochefort, R. M. and D. L. Peterson. 2001. Genetic and morphologic variation in *Phyllodoce empetriformis* and *P. glanduliflora* (Ericaceae) in Mount Rainier National Park, Washington. *Canadian Journal of Botany* 79: 178–191.

Shoal, R. Z. and C. A. Aubry. 2004. *The Status of Whitebark Pine on Four National Forests in Washington State.* Unpublished report, USDA Forest Service, Olympic National Forest, Olympia, WA.

Urbanska, K. M. 1994. Ecological restoration above timberline: demographic monitoring of whole trial plots in the Swiss Alps. *Botanica Helvetica* 104: 141–156.

USGS. 2003. *National Land Cover Characterization.* Available at landcover.usgs.gov/natllandcover.asp.

Vale, T. R. 1981. Tree invasion of montane meadows in Oregon. *American Midland Naturalist* 105: 61–69.

Van Vechten, G. W. III. 1960. *The Ecology of the Timberline and Alpine Vegetation of the Three Sisters, Oregon.* Ph.D. dissertation, Oregon State University, Corvallis.

Vivian, B. C. 1989. *A Survey and Assessment of the Cultural Resources in Cathedral Provincial Park, B.C.* Report prepared for the British Columbia Ministry of Environment and Parks, Permit No. 1988-80, Southern Interior Region, Kamloops.

Washburn, A. L. 1956. Classification of patterned ground and review of suggested origins. *Bulletin of the Geologic Society of America* 67: 823–865.

Washington Department of Fish and Wildlife. 1999. *Washington GAP Data Products.* Available at wdfw.wa.gov/wlm/gap/landcov.htm.

Weidman, N. R. 1984. *Seed Banks of Three Adjacent Subalpine Meadows: Olympic National Park, Washington.* M.S. thesis, University of Washington, Seattle.

Whitlock, C. 1992. Vegetation and climatic history of the Pacific Northwest during the last 20,000 years: implications for understanding present-day biodiversity. *Northwest Environmental Journal* 8(5): 5–28.

Wischmeier, W. H. and D. D. Smith. 1978. *Predicting Rainfall Erosion Losses: A Guide to Conservation Planning.* USDA Handbook No. 537. U.S. Government Printing Office, Washington, DC.

Zabinski, C., T. Wojtowscz, and D. Cole. 2000. The effects of recreation disturbance on subalpine seed banks in the Rocky Mountains of Montana. *Canadian Journal of Botany* 78: 77–582.

Zeglen, S. 2002. Whitebark pine and white pine blister rust in British Columbia, Canada. *Canadian Journal of Forest Research* 32: 1265–1274.

Zwinger, A. H. and B. E. Willard. 1972. *Land above the Trees: A Guide to American Alpine Tundra.* Harper and Row, San Francisco.