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

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

1.2.4 Incorporating Restoration Into Management

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

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

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

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

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

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

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

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

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

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

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

1.3 Overview of Plant and Soil Ecology

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

1.3.1 Environmental Components

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

1.3.1a Soil

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

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

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

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

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

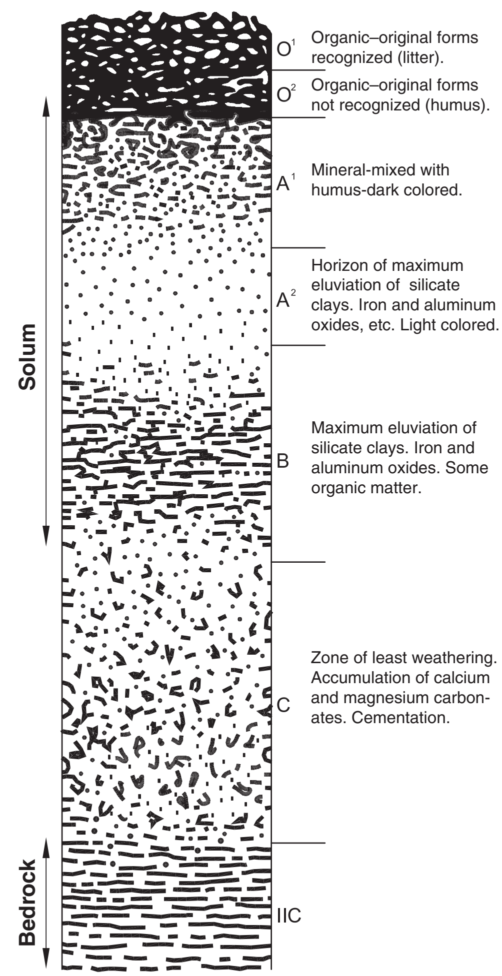

Figure 1–14—An idealized representation of soil horizons. The combined A and B horizons are called the *solum*, or *true soil*.

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

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

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

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

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

Soil texture is determined by the mix of particle sizes (figure 1–15). Sandy soils typically are well drained, droughty, and infertile. They are not highly susceptible to compaction, but they are erosive. Silty soils typically absorb and hold water well but do not become waterlogged. Because they hold water and nutrients well, silty soils are good for plant growth. However, they compact easily and the compacted soils can be erosive if they are dry. Clay soils drain poorly. They are often resistant to erosion. They compact easily when wet, but not when they are dry.

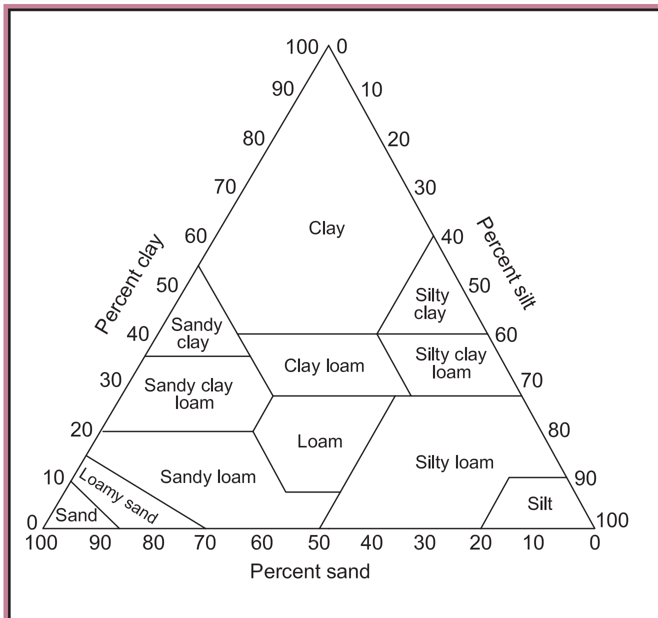

Figure 1–15—This pyramid shows the relationship between soil texture class and a soil's particle-size distribution. To use the diagram, find the percentages of any two of the particle sizes (sand, silt, or clay) on their respective lines. Then project lines inward from these points. Clay should be projected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

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

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

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

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

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

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

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

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

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

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

1.3.1b Plants

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

1.3.1c The Life Stages of a Plant

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

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

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

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

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

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

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

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

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

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

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

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

1.3.1d Plant Characteristics That Influence Restoration

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

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

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

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

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

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

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

1.3.1e Genetic Considerations

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

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

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

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

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

1.3.1f Microclimate

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

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

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

1.3.1g Animals

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

1.3.2 Ecosystem Processes

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

1.3.2a Hydrologic Processes

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

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

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

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

1.3.2b Succession

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

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

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

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

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

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

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

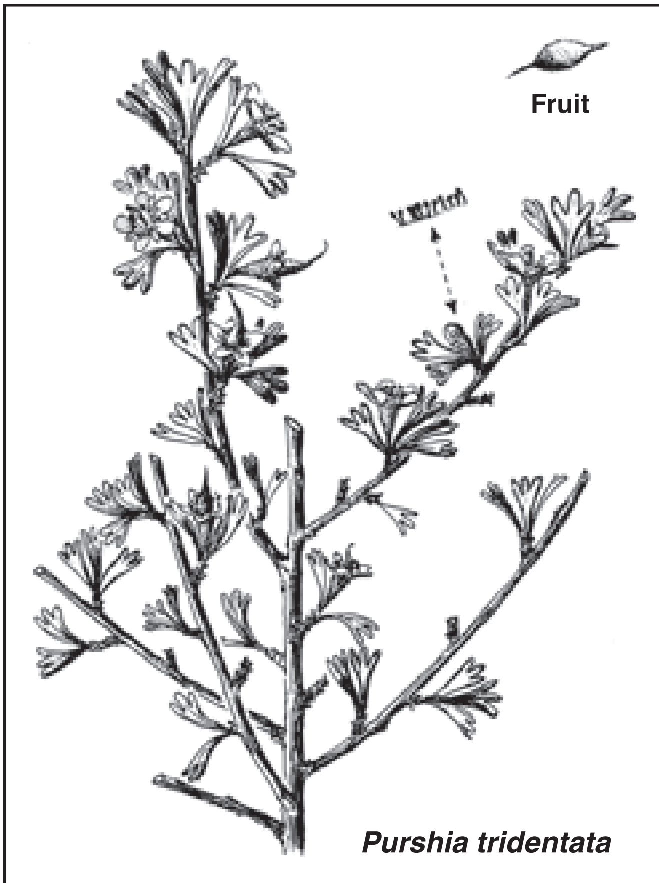

Figure 1–20b—Bitterbrush drawing courtesy of University of Washington Press (Hitchcock and Cronquist 1976).

1.3.2c Biotic Interactions

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

1.3.2d Plant-Plant Interactions

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

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

1.3.2e Plant-Soil Interactions

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

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

1.4 Concluding Thoughts

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

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

Chapter 2