3 Vegetation

Along with water, vegetation is probably the most important resource component affecting visitor selection of recreation sites. Vegetation adds to site desirability by providing shade, screening for campsite privacy, and attractiveness or botanical interest. At the same time, vegetation can be susceptible to damage, particularly from recreational trampling. Consequently, it is often highly altered on recreation sites. Of all changes that occur as a result of recreation, impacts on vegetation are the most readily evident to users (Fig. 1).

VEGETATION IMPACT PARAMETERS

In contrast to the properties of soils investigated, researchers have studied fewer vegetational parameters in their attempt to describe the impacts of recreational use. Moreover, understanding these parameters requires less specialized knowledge about vegetation ecology than is required for soil ecology. Consequently, we will not need to devote as much space to describing vegetational parameters as we did for soils.

Amount of Vegetation

The most common impact parameter studied is vegetation cover, usually defined as the percentage of the ground area covered by the vertical projection of aboveground plant parts. Usually the researcher will place some sample unit over the vegetation, such as a quadrat 1 m on each side, and estimate the percentage of the quadrat area covered by vegetation. For example, Cole (1982) estimated vegetation cover on campsites, using the mean cover of vegetation in fifteen 1 m^2 quadrats systematically dispersed around each site. Other standard techniques for measuring or estimating cover include line intercepts and point intercepts (Marion 1991; Mueller-Dombois and Ellenberg 1974).

Regardless of the technique, the intent is to provide a measure of the amount of vegetation present in the area under study. By comparing such a measure on a recreation site before and after recreational use, the effects of recreation on vegetation can be identified. Where recreational use has already occurred, vegetation impacts can also be identified by comparing vegetation cover on recreation sites with cover on adjacent undisturbed sites (Cole 1995a). The assumption, in this case, is that the undisturbed site

FIGURE 1. Impacts to vegetation in zones above treeline are often severe, long lasting, and readily visible to users for some distance. (*Photo*: W. E. Hammitt.)

(the control) is similar to what the recreation site was like before it was used. Thus, this means of evaluating impact will be accurate only if researchers carefully select controls that are environmentally similar to recreation sites. This requires considerable experience; however, the use of control sites is the preferred procedure for documenting relative ground cover change between used and unused recreation sites.

Although uncommon in the impact literature, other measures of amount of vegetation that have been used are density and biomass. Density is simply a count of the number of individual plants in some unit area (e.g., 10 trees/100 m^2). Density can be useful for large, discrete individuals such as trees; it is less useful in working with grasses and plants that grow in clumps where it is difficult to distinguish between individuals. Thus, it has become standard to measure density of trees and sometimes shrubs and cover of the ground level of vegetation. Biomass is a measure of the weight of vegetation in a unit area. It is determined by clipping the vegetation, drying it to remove water, and then weighing it (Sun and Liddle 1991). Although this provides a more objective measure of amount of vegetation than cover does, this method is destructive and quite time-consuming. Therefore, it is seldom used.

Vegetation Composition

In addition to recording amount of all vegetation, it is common also to record cover for individual species, species diversity, and frequency. Plant height and form are sometimes recorded (Sun and Liddle 1991). This information is used to characterize species composition, particularly of the ground level vegetation. The term *species composition* is used to refer to the mix of species that occupies any site. As with total vegetation, recreational impacts on the cover of individual species can be identified. Some researchers have grouped species into classes of particular interest. This allows them to study the effect of recreation on such classes of plants as exotic species and species exhibiting different growth forms. Exotic species are those that are not native to any given area. Such species commonly increase in importance on recreation areas, thriving on disturbed areas where native species have difficulty growing. Growth forms are classes of species grouped on the basis of similarities in their structure, form, and function. Studying how different growth forms respond to recreation use has been helpful in understanding how and why different plants vary in their susceptibility to impact (Cole 1995a).

Tree Condition

A third common parameter of interest is tree condition. In most cases, researchers have documented the percentage, number, or density of trees that have been inflicted with certain types of damage such as root exposure or severe scarring. A few studies have also tried to relate tree growth to recreational use to determine what effect recreation has on growth.

IMPACTS ON VEGETATION

Most vegetation types have a vertical structure that consists of a number of horizontal strata. Although not common to all vegetation types, three important and distinct strata are the ground cover layer, shrubs and saplings, and mature trees. In the following discussion we will explore recreational impacts on each of these three layers.

Ground Cover

Ground cover vegetation is profoundly impacted by visitor use, particularly as a result of trampling. Trampling affects ground cover vegetation both directly and indirectly. Ground cover is directly affected where trampling breaks, bruises, and crushes plants. It is indirectly affected where trampling causes soil compaction and other soil changes which, in turn, lead to changes in vegetation.

The direct effects of trampling are usually detrimental to plants. Although growth of a few species is stimulated by low levels of trampling, most species exhibit reduced abundance, height, vigor, and reproductive capacity on recreation sites. Where trampling is heavy and/or vegetation is fragile, plants are killed outright. Death occurs when plants are ripped out of the ground, have their regenerative tissues destroyed, or, in the case of annuals (plants that live for only one season), lose their ability to reproduce. Less severe trampling damage causes breakage without death; plant stems are knocked back and leaves are torn off. This reduces the area available for photosynthesis. Loss of photosynthesis then leads to reductions in plant vigor and can affect the ability to reproduce. For perennials (plants that live a number of years), repeated loss of photosynthetic area can ultimately cause death of the plant.

Problems resulting from direct impact to aerial plant parts are compounded by the problems of growing and reproducing in compacted soils. Compaction increases the mechanical resistance of the soil to root penetration. As was illustrated in Fig. 8 in Chapter 2, plants growing in soils with high bulk densities have fewer roots that extend only a short distance away from the plant. An important function of these roots is to grow into areas where water and nutrients can be extracted. When water and nutrients are depleted close to the plant, roots must be able to extend farther away from the plant. Compaction makes this more difficult; as a result, plants cannot extract sufficient quantities of water and nutrients from the soil. This problem is compounded by two other consequences of compaction. Loss of macropores in the soil reduces soil aeration, because most oxygen resides in the larger pores in the soil. Oxygen shortages also inhibit root growth, which in turn makes extraction of water and nutrients more difficult. Compaction also reduces water infiltration rates. With less water entering the soil, plant roots will more rapidly exhaust soil moisture adjacent to the plant. This accentuates the need for a large and healthy root system under conditions in which the size and health of root systems are deteriorating. Such indirect effects should cause more serious problems in environments where moisture and/or nutrients are scarce.

Compaction also inhibits the germination, emergence, and establishment of new plants. Seeds lying on a compacted surface crust are prone to dessication and less likely to receive proper incubation and moisture. Studies have shown that germination success is usually greatest on heterogeneous surfaces with a diversity of microsites (Harper, Williams, and Sagar 1965); a smooth, compacted surface does not provide such a diversity of microsites so germination is reduced. Should germination occur, a strong surface crust will make it difficult for the radicle (the incipient primary root) to penetrate the soil to provide stability, water and nutrition. Even if the seedling successfully germinates and emerges from the soil, a number of indirect impacts make premature death likely.

The microclimate of trampled sites is more severe than in untrampled areas. Both vegetation and organic matter serve to moderate temperatures, keeping them from getting too high during the day or too low at night. Trampling, by removing vegetation and organic matter, indirectly subjects seedlings to a greater likelihood of both heat injury and freezing. Another common cause of death is frost heaving, a process in which freezing and thawing of the soil physically lift seedlings out of the soil. Although frost heaving does occur on undisturbed sites, it is most common in bare mineral soil, particularly soils that have been compacted.

The ultimate result of most of these effects of trampling is a reduction in amount of vegetation, usually expressed as a loss of vegetation cover. This type of impact is particularly pronounced on campsites. Even in wilderness areas campsites commonly lose most of their vegetation cover. For example, cover loss on campsites in the Eagle Cap Wilderness, Oregon, average 87 percent (Cole 1982); the average loss on sites in the Boundary Waters Canoe Area Wilderness, Minnesota, was 85 percent

(Frissell and Duncan 1965). Cover loss on developed campsites is sometimes less pronounced because of more active maintenance programs and more durable vegetation. On developed campsites in Rhode Island, for example, Brown, Kalisz, and Wright (1977) found cover loss to be only about 50 percent. Loss of vegetation cover usually exposes underlying organic matter unless this layer has also been worn away and mineral soil or rock is exposed.

Ground cover vegetation can also be destroyed when it is disturbed by off-road vehicles. In the Algodones Dunes area of southern California, areas used by dune buggy and other off-road vehicle enthusiasts had only about 5 percent as many herbaceous plants as undisturbed areas (Luckenbach and Bury 1983).

Many studies have found that the loss of vegetation cover on lightly used sites is nearly as substantial as the loss on heavily used sites. This has been illustrated most frequently on wilderness campsites. For example, in studies in three western wilderness areas, cover loss on sites used only a few nights per year averaged between 55 and 71 percent (Fig. 2). The curve that describes the relationship between vegetation loss and amount of use is not a straight line; it is curvilinear or hyperbolic, to be more precise. Some trampling studies (e.g., Cole 1985b) have found a linear relationship between certain vegetation type covers and the logarithm of amount of use. Cover loss increases rapidly with initial increases in use. Beyond some use threshold the rate of loss decreases as loss approaches 100 percent (Cole 1995b).

The finding that vegetation loss is so severe even on lightly used sites illustrates the susceptibility of ground cover to impact. Although susceptibility varies greatly between vegetation types, a topic that will be discussed in more detail in Chapter 8,

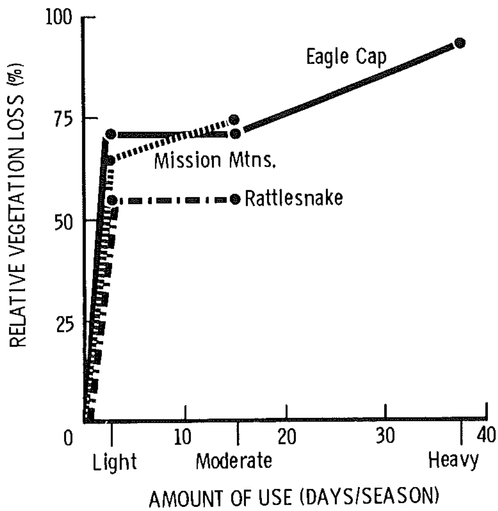

FIGURE 2. Median values of relative vegetation loss plotted in relation to amount of use in the Eagle Cap, Mission Mountain, and Rattlesnake Wildernesses. For the Eagle Cap campsites, the numerical use frequencies are estimates. (*Source*: D. N. Cole.)

the curvilinear relationship between amount of use and vegetation cover is most common. This has important implications for management, implications that will be discussed more fully in Chapters 9 and 12.

Loss of vegetation usually occurs very rapidly once use of campsites begins. LaPage (1967) followed changes on developed campsites in old field grasslands in Pennsylvania over the course of the first three years they were used. After the first year of use, an average of 45 percent cover was lost on the campsites (Fig. 3). Plant cover increased over the winter when no recreational use occurred and then declined over the next use season. However, total cover at the end of the second and third use seasons was actually greater than it had been after the first season of use.

What was happening on these campsites was that the original native occupants of the sites were being replaced by new species that were more resistant to trampling. Although vegetation cover increased from the end of the use season in 1963 to the end of the use season in 1965, the total number of species declined from 29 in 1963 to 23 in 1964 and 17 in 1965. This compares with 37 species found on the sites before use began. Many species were being eliminated by camping, but a few species were increasing in importance. As camping disturbance increased and competition with native species decreased, these trampling-resistant species were able to spread and increase total vegetation cover on the sites. A number of new species actually invaded the site. Four species that were not present before camping began appeared and spread on the sites in subsequent years. However, even with this increase cover remained reduced by about one-third.

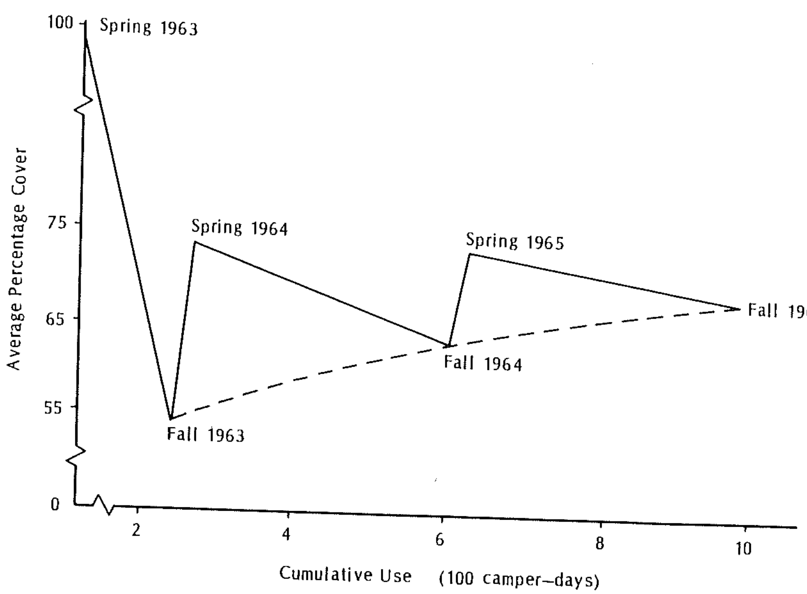

FIGURE 3. Changes in vegetation cover following the initial development and use of a car campground in Pennsylvania. (*Source*: LaPage 1967.)

Beyond loss of cover, this study illustrates several other common vegetation impacts. One is the decline in number of species—a characteristic of plant communities known as species richness. Species richness is one of the components, along with the relative abundance of individual species, of the concept of species diversity. A reduction in species richness almost always occurs where recreational use levels are high. At high-use levels only trampling-resistant species can survive, if any species can. The number of trampling-resistant species is always less than the number of original occupants of the site. However, the highest species richness usually occurs in areas that receive low to moderate levels of use. In such places the original occupants will be reduced in abundance but not eliminated. Less competition with these natives encourages the invasion and spread of trampling-resistant species. Richness is high because both the original occupants and the trampling-resistant invaders occupy the site simultaneously.

Another type of impact reflects the fact that species differ greatly in their resistance to impact. As seen in the Pennsylvania campsite example, some of the original species that occupied the campsites were eliminated much more rapidly than others; indeed, some species actually increased in cover, and other species invaded the site. The most common species before use, cinquefoil, was eliminated entirely after three seasons of use, whereas bluegrass, originally found in only a few places, became the most common species on the campsites. Over time such changes led to development of a plant community with a different species composition than was originally there.

Change in species composition is usually evaluated by reporting differences in the cover of all individual species, either over time or between recreation sites and undisturbed controls. Such lengthy lists of species make it difficult to compare the severity of shifts in species composition in different places. To provide an index of change in species composition, Cole (1978) proposed an index that measured the dissimilarity in composition between two sites. This index, the floristic dissimilarity index, can vary between 0 and 100 percent. A value of 0 means that both sites are identical in terms of both the species there and their relative abundance. Realistically, this value is not possible in nature; even under undisturbed conditions there is considerable variation in species composition, often on the order of 25 percent or so. A value of 100 percent means that the two sites have no species in common.

This index has been used to quantify change in species composition on campsites in a number of recreation areas (Cole 1995b; Marion and Cole 1996). On campsites in the Boundary Waters Canoe Area, the original forest-floor occupants tend to be fragile, and there are a number of trampling-resistant species to invade campsites. Consequently, compositional shifts are pronounced, and the floristic dissimilarity index averaged 88 percent (Marion 1984). On campsites high in the mountains of the Rattlesnake Wilderness, Montana, most of the native dominants are resistant to trampling, and few invader species can grow successfully at such high elevations. The floristic dissimilarity there averaged only 27 percent, little more than one would expect when comparing undisturbed plant communities (Cole and Fichtler 1983).

Whether any individual species will be resistant to trampling or not is largely dependent on its structure or form and characteristics of its life cycle. Of importance are the morphological and physiological characteristics of individual species and plant forms that are tolerant of disturbance (Cole, 1987; Speight 1973). Morphological characteristics that generally make a plant more tolerant include:

1. A procumbent or trailing, rather than erect, growth form
2. A tufted growth form
3. Presence of thorns or prickles
4. Stems that are flexible rather than brittle or rigid, particularly if they are woody
5. Leaves in a basal rosette
6. Small, thick leaves
7. Flexible leaves that can fold under pressure
8. Either very large or very small structure

Physiological characteristics that increase tolerance include:

1. Ability to initiate growth from intercalary as well as apical meristems
2. Ability to initiate seasonal regrowth from buds below the surface
3. Ability to reproduce vegetatively and sexually
4. A rapid growth rate

Although no species will possess all of these characteristics, many highly resistant species will possess a number of them. For example, bluegrass, the species that increased so dramatically on the Pennsylvania campsites, is capable of growing low to the ground (it is capable of erect growth when undisturbed and prostrate growth when disturbed) and has flexible folded leaves, intercalary meristems, buds protected below the ground surface, and the ability to reproduce from rhizomes and initiate rapid growth when injured. For these reasons it is a common lawn grass as well as a common invader of recreation sites. For lists of other species tolerant of impacts, see Cole (1987, 1995a).

Liddle (1991) summarizes many of the 12 characteristics listed earlier into four biological features that promote resistance and recovery from recreation impacts. The first feature is small size; for example, plants not able to grow in rosette, creeping, or other low-growing forms do not survive and rarely appear in trampled flora. The most important characteristics of the second feature, morphology, seem to be the location of the vegetative bud or persistent stem apex of different life forms of plants (Fig. 4). Buds and meristems in contact with the soil surface and cushioned by clusters of folding leaves tend to survive best. In terms of anatomy, two features are important to plant survival. Stems composed of small cells (≤ 0.1 mm) can withstand greater compression without distortion than larger-celled or hollow stems. Second, flexibility of stems and leaves aids survival—lignified tissues, for example, tend to be more rigid and break easily when trampled. The final biological feature concerns survival strategies, which involve the theoretical considerations of morphology and

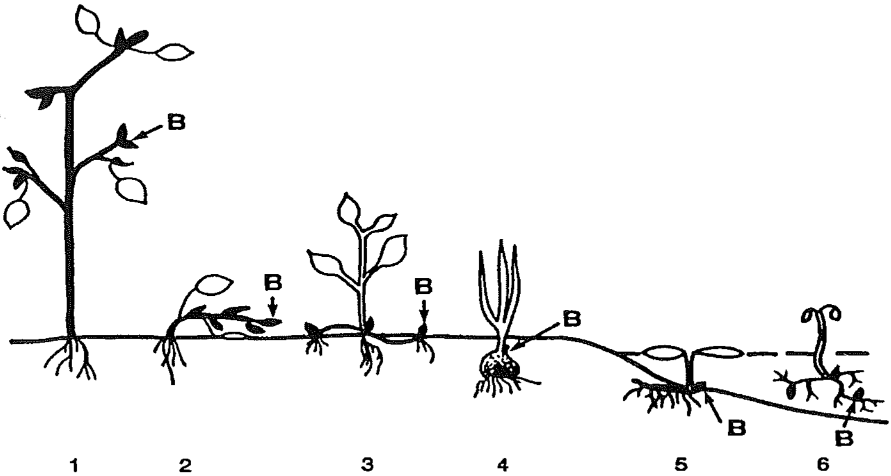

FIGURE 4. The life forms of plants provide a nontaxonomic way of grouping plant species according to their morphology, based on the position of the vegetative buds or persistent stem apex that survives over winter or periods of drought. *(1) Phanerophytes:* woody plants with buds more than 25 cm above soil level. *(2) Chamaephytes:* woody or herbaceous plants with buds above the soil surface but below 25 cm. *(3) Hemicryptophytes:* herbs (very rarely wood plants) with buds at soil level. *(4) Geophytes:* herbs with buds below the soil surface. *(5) Helophytes:* marsh plants. *(6) Hydrophytes:* water plants. *Therophytes*—plants that pass the unfavorable season as seeds—are not shown in the figure. *Cryptophytes* have buds below ground or water level; that is, this group includes geophytes, helophytes and hydrophytes. *Protohemicryptophytes* are hemicryptophytes with leafy stems. B, perennating bud. (*Source*: Liddle 1991.)

anatomy in relation to plant resistance and the physiology of plant recovery from impacts. For example, Bayfield (1979) compared the resistance and recovery response of different species and found there were three groups of species with respect to trampling susceptibility: (1) those most susceptible—with high initial damage and poor recovery, (2) those with moderate susceptibility—moderate to high initial damage and fairly good recovery, and (3) those with low susceptibility—low to moderate damage followed by an increase in cover. More recent studies by Cole (1995a) in mountainous regions and Sun and Liddle (1993) in tropical/subtropical regions have identified species and vegetation types that demonstrate the various combinations of resistance and recovery survival strategies (see Chapter 8).

Many of the most resistant species are exotics, many of which are native to Eurasia. At high elevations in the mountains, exotic species are uncommon. At lower elevations, however, exotics often dominate the vegetation along trails and on campsites. In the Boundary Waters Canoe Area Wilderness, for example, Marion (1984) found at least one exotic species on 62 percent of the campsites he surveyed. One campsite had 12 different exotic species. Three exotic species were among the 10 species found on the largest number of campsites. On campsites in the Bob Marshall

Wilderness, Montana, three of the four most common species on campsites were exotics (Cole 1983).

Generally, researchers have found that graminoids (grasses and grasslike plants such as sedges and rushes) possess more adaptations and survival strategies that allow them to resist impact than other growth forms. For example, in a study of 18 vegetation types, a species of sedge (*Carex nigricans*) was most resistant to trampling, and a wood fern (*Dryopteris campyloptera*) was the least resistant. In the sedge type, substantial cover was lost only after 500 trampling passes. Just 25 passes were required to reduce the fern cover by 33 percent (Cole 1995a). Forbs, herbaceous plants other than graminoids, vary greatly in their resistance. Low-growing, tufted forbs with a basal rosette of small, tough leaves are common survivors on recreation sites. Two common examples, both exotic in the United States, are white clover and common plantain. Forbs that grow in the shade of deep forests are at the other extreme. In trying to gather in as much light as they can, they tend to be tall with large, think leaves. Leaves generally lack tough outer layers so that absorption of light is maximized. They invest more of their energy in producing photosynthetic tissue than in producing tough support systems such as stout stems and branches. These adaptations make them highly susceptible to trampling damage. Low-growing shrubs are intermediate in their resistance to damage. They can usually survive low levels of trampling because of a tendency to have small, tough leaves and woody stems. Their stems are often brittle, however, and so they are usually eliminated at moderate use levels. The loss of shrubs on recreation sites is accentuated by slow rates of regrowth once stems are broken.

Research during the 1990s has concentrated on the vulnerability/durability of vegetation types and species over larger geographical and environmental areas (versus site studies) to better understand patterns of vegetation resistance and recovery toward trampling impacts (Cole 1995a; Sun 1992; Sun and Liddle 1993). Cole reported on the response of 18 vegetation types in five separate mountain regions of the United States, and Sun and Liddle surveyed eight tropical/subtropical areas in Australia. Results of these studies indicated that, in general, (1) plant species in the tropics and temperate areas responded essentially the same to trampling impacts, (2) plant morphological characteristics explained more of the variation in resistance, tolerance, and recovery from trampling than site characteristics, (3) resistance was primarily a function of vegetation stature, erectness, and whether plants were graminoids, forbs, or shrubs; however, even different species of grasses varied in their vulnerability to trampling (Sun and Liddle 1991), (4) recovery or resilience was primarily a function of whether plants had perennating buds located above the ground surface (negatively related), and high growth rate may be an essential feature of species that use a recovery strategy to tolerate trampling, (5) tolerance, the ability of vegetation to withstand a cycle of disturbance and recovery, was correlated more with recovery than resistance, and (6) resistance and recovery of individual species were negatively correlated (Fig. 5). Characteristics that promote the ability initially to resist trampling damage differ from those that enable plants to recover quickly. For example, plants that are resistant to trampling

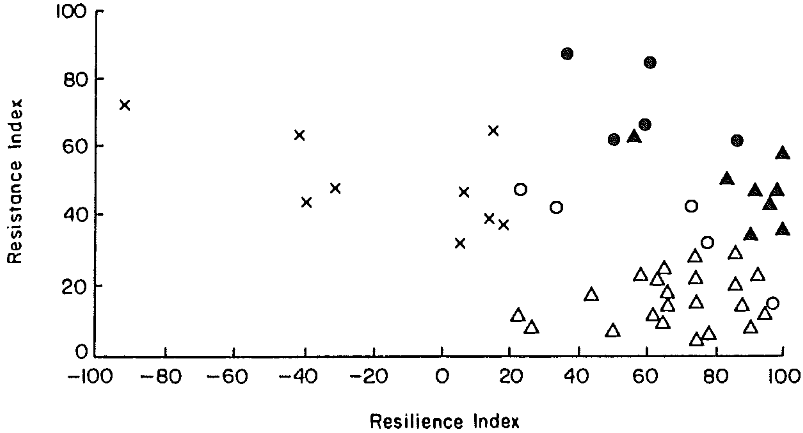

FIGURE 5. Resistance and resilience indices (%) for individual species, classified by morphology as chamaephytes (x), erect graminoids (o), nonerect graminoids (•), erect forbs (▲). Resistance index is mean relative cover after 0–500 passes. Resilience index is mean increase in cover during the year after trampling, as a percentage of the cover loss recorded two weeks after 0–500 passes. Note the inverse relationship between resistance and resilience for most species, but the high resistance/resilience for nonerect graminoids and forbs. (*Source*: Cole 1995a.)

tend to have low growth rates; plants with fast growth rates appear to use a recovery strategy.

Tree seedlings are particularly sensitive and readily killed when trampled. Even in wilderness areas tree seedlings are almost completely eliminated on all but the most lightly used campsites. In the Eagle Cap Wilderness the average number of tree seedlings on a campsite of average size (200 m^2) was only 6. The number on a comparably sized undisturbed site was more than 50. This represents an average loss of over 90 percent of all seedlings. Even on the most lightly used sites, those used no more than about five nights per year, about three-fourths of all seedlings had been eliminated (Cole 1982). Similar near-complete losses of tree reproduction have been reported wherever campsite impacts have been studied. Such losses are likely to be even more pronounced on more heavily used, developed sites. For example, in a survey of 137 developed Forest Service camping and picnic sites in California, Magill and Nord (1963) found no seedlings at all on more than one-half of the sites. They also state that, where present, the continued survival of tree seedlings is doubtful.

Loss of ground cover vegetation occurs in campsites wherever trampling occurs. Along trails, ground cover is eliminated on the tread, either during construction or shortly after the start of use. Adjacent to the tread is a trailside zone that receives some trampling pressure and is also affected by habitat changes such as increased light levels caused by brush and tree removal during trail construction. This zone certainly experiences a change in species composition (Boucher, Aviles, Chepote, Dominguez Gil, and Vilchez 1991; Leung and Marion 1996). Usually, vegetation cover will also be reduced, but sometimes the habitat changes will result in an increase in cover there. Cole (1978) studied loss of cover and change in species composition in the trailside zone in eight different vegetation types in the Eagle Cap Wilderness. Cover loss adjacent to trails was as high as 73 percent in some of the forested types and as low as 12 percent in subalpine meadows. Floristic dissimilarity varied from 37 to 82 percent; the most pronounced shifts occurred in the forested vegetation types.

Where trampling pressure is low, the height of the vegetation can be reduced without incurring a loss of vegetation cover. Vegetation with reduced stature is commonly found at the periphery of campsites and along the edge of trails. This vegetation forms a pronounced zone intermediate between the barren center of the campsite or trail and the undisturbed vegetation beyond. Lightly used trails, particularly those that were user-created, are also characterized by a short but complete vegetation cover. Other changes in plant morphology and physiology where plants are disturbed but not destroyed include a reduction in leaf area, carbohydrate reserves in roots, flower density, and number of seeds per flower (Liddle 1975; Hartley 1976; Sun and Liddle 1993). Liddle (1975) found that 400 passes by a light vehicle reduced the leaflet area of a relatively resistant clover species by 57 percent. When "trampled" by a tractor six times, the average number of flower heads on a species in the pea family decreased from 29 to 1; no seed pods were found on trampled plants. With light foot traffic the number of branches can sometimes increase as a response to frequent damage of terminal buds.

An additional source of impact on ground vegetation, in many Western areas particularly, is grazing and trampling by stock. The trampling effects of stock are generally similar to those caused by humans, except that the potential for causing impact is much more pronounced. Horses weigh much more than humans, and their weight is concentrated on a small bearing surface. This greatly increases the pressure stock exert on both vegetation and soil. Moreover, shod hooves can cause substantial gouging and ripping of the ground. Grazing effects also lead to cover losses and changes in species composition. Changes in composition are accentuated by the fact that stock prefer to eat certain species if they are available. These preferred species, because they are defoliated more frequently, will often decrease and be eliminated more rapidly than other species.

Few data on recreation stock impacts on meadows exist (Cole 1987). Cole (1981) compared the cover and composition of some lightly and heavily grazed mid-elevation meadows in the Eagle Cap Wilderness. The more heavily used meadows had about 30 percent less cover than the lightly used meadows. Graminoids, which are generally more palatable than forbs, comprised only about 35 percent of the cover on the heavily used sites, compared with 80 percent on lightly used sites. The heavily grazed meadows also had more exotic species and more annuals. More detailed and longer-term meadow surveys have been conducted in Sequoia/Kings Canyon National Parks (DeBenedetti and Parsons 1983). More than 40 years of research has documented reduced vegetation cover, erosion, and "weedy" species invasion in meadows, as well as a better understanding of annual fluctuations in the productivity of major plant associations and the response of each association to different levels of grazing. The long-term studies have led to the development of meadow-stock use management and monitoring plans for different representative meadows in the parks.

Shrubs and Saplings

Low-lying shrubs suffer from trampling because they are part of the ground cover vegetation. Native blueberries (*Vaccinium*) have been found to be particularly susceptible, as they have poor recovery ability after initial trampling (Cole 1995a). Larger shrubs and saplings are usually large enough to avoid most of the direct effects of trampling. Most impact to this taller vegetation layer is the result of either damage caused by off-road vehicles or the conscious removal of shrub and sapling stems.

Both terrestrial off-road vehicles and snowmobiles can affect shrubs and saplings. Shrub cover was reduced 90 percent in an off-road vehicle area in southern California. Cacti and thorny plants that are usually spared from trampling damage can be run over and killed by vehicles.

Snowmobiles can be particularly damaging to shrubs and saplings. Ground cover plants are likely to be protected by the snow cover, although this is not the case if snow cover is shallow. Mature trees are likely to incur only trunk scars. Shrubs and small saplings, however, are often stiff and brittle during the winter and are readily snapped off when run over by snowmobiles. In some cases, damage to shrub stems causes them to put out sucker shoots. Wanek (1974) found that "most shrubs increase (number of stems and cover) where snowmobiles travel, primarily because of vegetative propagation." He points out that this may not continue indefinitely, because of disease or eventual failure to maintain the large root system of individual plants.

Removal of shrub and tree stems occurs along trails to make it easier for hikers and stock to use a trail. For example, standards on Forest Service trails in wilderness specify removing brush along a corridor 8 ft wide and 10 ft high. In more developed settings, removal of shrubs and saplings is even more pronounced. In terms of biomass removed, trail construction and maintenance are the activities that cause the most impact to shrubs and saplings in wildland recreation areas. The major exception would be in roaded areas where road construction and maintenance remove even more vegetation.

Although not as much biomass is involved, concern with removal of shrubs and saplings usually centers on campsites. Here, loss of stems occurs as a result of the development and expansion of sites as well as the felling of stems for poles and firewood. In the intersite zones of a developed campground in Michigan (intersite zones are the lightly used portions of the campground between high-impact centers of activity—refer to Chapter 6), McEwen and Tocher (1976) found only 76 saplings per acre compared with 338 per acre in adjacent unused portions. Around long-established shelters along the Appalachian Trail in Great Smoky Mountains National Park, saplings less than 3 in. in diameter often cannot be found within 200 ft of shelters; they have been cut down and used for firewood. On campsites in Eagle Cap Wilderness, one-third of the trees had been felled; most of these felled trees were sapling size (Cole 1982).

Perhaps the most serious consequence of this type of impact is its long-term effect on maintenance of forested campsites. Removal of saplings from the immediate vicinity of campsites is reducing the source of new trees to replace the current overstory when it eventually succumbs to old age. Tree reproduction is almost nil as a result of trampling. Removal of the few stems that do make it into the sapling size class forecasts the eventual conversion of forested sites into open vegetation types. Because campers have been shown to prefer the shading and privacy provided by both shrubs and trees (Cordell and James 1972), this is a highly undesirable change.

Mature Trees

The major impacts to mature trees on recreation sites result from mechanical damage. Much is caused consciously, if thoughtlessly, by visitors through a diverse set of acts that include removing limbs, driving nails into trunks, hacking trees with axes, peeling bark to use as kindling, and felling trees for tent poles or firewood. Other impacts are caused unconsciously; for example, trees are scarred by lanterns, and roots are exposed when stock are tied to trees. Finally, considerable impact to trees is caused by management. Examples include clearing trees along trails and in campsites and removing hazard trees in danger of falling on people.

In an intensive survey of tree damage on campsites in the Eagle Cap Wilderness, Cole (1982) found that more than 90 percent of the mature trees had been scarred, felled, or had cut or broken branches (Fig. 6). Damage to many of the trees was relatively minor—lower branches had been broken or nails had been driven into trunks. Twenty-seven percent of these trees, however, bore trunk scars from chopping. Of these scars 22 percent were larger than 1 ft^2, and 67 percent were located below breast height, conditions under

FIGURE 6. Tree damage on a campsite in the Eagle Cap Wilderness, Oregon. (*Photo*: D. N. Cole.)

which the probability of decay is particularly high for these spruce and fir species. Another 33 percent of the trees on the campsites had been cut down.

Despite this level of damage to overstory trees, there was little evidence of recreation-related tree mortality or even loss of vigor, except where trees had been felled outright. The fact that more than six decades of recreational use have had little noticeable effect suggests that premature mortality of the overstory may not be a serious problem. Most other studies have also found little evidence of recreation-caused tree mortality. Recreation-caused loss of vigor and death occur most commonly where soils are thin and/or droughty or where trees are thin-barked and particularly susceptible to decay. Mortality of trembling aspen, a widespread thin-barked tree, was studied on 17 developed campgrounds in the Rocky Mountains. The trees were dying at a rate of about 4 percent per year, mostly as a result of canker diseases following mechanical injuries caused by campers (Hinds 1976).

Another place where tree mortality has been a serious problem is the Boundary Waters Canoe Area Wilderness. Merriam and Peterson have followed change over time on a small number of campsites established by the Forest Service in 1967. Just five years after use began, the average percentage of original trees that had died was 15 percent; after 14 years 40 percent of the trees had died (Merriam and Peterson 1983). Aspen and birch dominate a number of these sites; their thin bark and the tendency for campers to peel off bark for kindling make them particularly susceptible to damage. Thin soils and pronounced erosion are also characteristic of these canoe-camping sites. It is not uncommon for almost all of the soil to be removed from surface tree roots. Once this occurs, death may follow.

Exposure of tree roots is a common occurrence on trails, river and lake banks, and campsites. Of 19 campsites with trees in Cole's Eagle Cap survey, 17 had trees with exposed roots. On a typical campsite about one-third of the trees had exposed roots. In the Boundary Waters, 84 percent of the trees on campsites surveyed by Marion (1984) had exposed roots. Once exposed, roots can suffer mechanical damage. Root exposure also makes trees more prone to wind throw.

Because trees are longer-living forms of vegetation, managers and researchers have been interested in the temporal and spatial variation of long-term impacts to trees (see Chapter 7). Long-term studies indicate that spatial impacts (i.e., site expansion) are more important than temporal impacts to trees. Also of concern is the amount of seedling establishment over time on concentrated use sites. In the Delaware Water Gap National Recreational Area, the mean density of trees shorter than 140 cm on campsites (size classes considered indicative of tree reproduction) was only 9 percent of the density of control sites (Marion and Cole 1996, p. 524). In addition, 19 percent of the overstory trees on campsites had been felled and 77 percent of standing trees had been damaged.

In areas that receive large amounts of overnight stock use, tree damage can be especially pronounced. Most of this additional damage reflects the common practice of tying stock to trees. When tied in this way, most animals will paw up the ground, causing erosion and exposure of tree roots. Rope burns on the tree trunks leave scars, and on small trees can girdle and kill the tree. In addition, parties that travel with stock are more likely to carry heavy canvas tents that require felled trees for tent

TABLE 1. Tree Damage on Campsites Used Primarily by Backpackers, Private Horse Parties, or Outfitted Parties[a]

	Seedling Loss		Damaged Trees		Felled Trees		Trees with Exposed Roots	
Type of Use	Median	Range	Median	Range	Median	Range	Median	Range
	Percent		Number of Trees in Disturbed Area					
Backpacker	100	100 a	5	3–29 a	0	0–8 a	1	0–4 a
Horse	100	92–100 a	56	21–180 b	8	0–33 b	25	10–38 b
Outfitter	100	100 a	100	23–500 b	15	3–250 b	37	13–100 b

[a]Any two sets of median and range values followed by the same letter are not significantly different at the 95 percent confidence level, using the randomization test for two independent samples. Seedling loss is relative change.

poles. They are also more likely to carry axes and saws capable of felling trees for firewood. Not every stock party causes these avoidable types of impact, but enough do for tree damage in horse camps to be particularly pronounced.

To illustrate this difference, Cole (1983) compared the number of damaged trees on backpacker, horse, and outfitter campsites in the Bob Marshall Wilderness, Montana (Table 1). Backpacker sites were used only by backpackers; horse sites were used primarily by private horse parties, usually for only a few nights at a time; outfitter camps were sites occupied by outfitted parties for long periods of time, particularly during the fall hunting season. Seedling loss is the same—100 percent—on all three classes of sites; this damage is the inevitable result of trampling and does not vary with type of use. In contrast, there are large differences in damage to mature trees between the three types of sites. This damage is avoidable and related to the type of use occurring on the site.

Likewise, mechanical damage on developed sites can be much more common and serious than that on backcountry sites. Common types of damage on such sites include lantern scars and nails driven into trees to hang objects. In most older national forest and national park campgrounds, mature trees close to tables have numerous scars from gas lanterns. These scars, caused by heating, can weaken trees, particularly if the trees are thin-barked. Once weakening occurs, trees are more prone to breakage and, as hazard trees, must be removed by management. In recent years metal lantern holders have been erected on most sites to avoid this problem. The fact that people tend to stay much longer at developed sites accessible by road and can carry much more equipment provides more opportunity for damage; mature trees bear much of the brunt of this damage.

SUMMARY

1. Trampling affects vegetation both directly and indirectly. These interrelationships are diagrammatically presented in Fig. 7. Breakage and bruising reduce plant vigor and reproductive capacity; severe trampling kills plants directly. Plant vigor

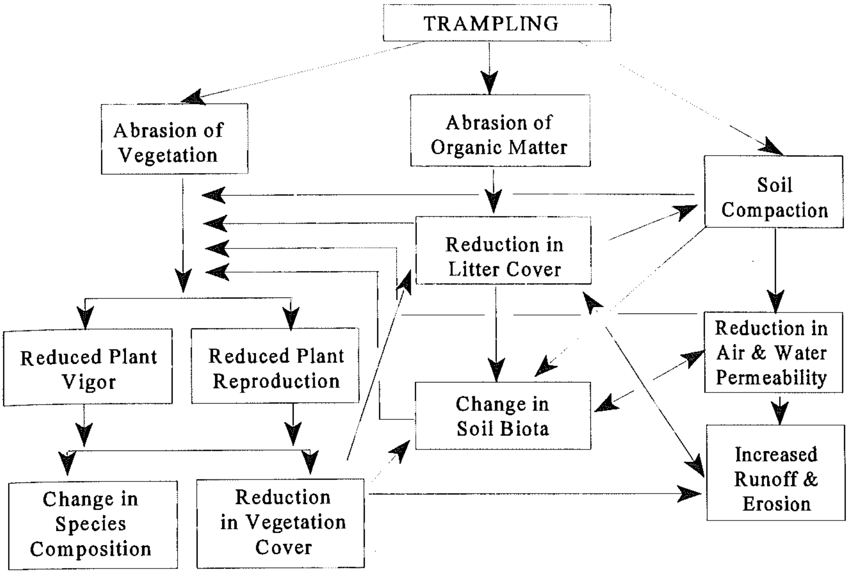

FIGURE 7. A conceptual model of trampling effects, partly based on Liddle (1975) and Manning (1979). Note the numerous reciprocal and cyclic relationships between soil and vegetational impacts.

and reproductive capacity are also reduced as a result of the soil changes described in Chapter 2. Shrubs and saplings are removed to expand the campsite, clear the trail, or collect firewood. Mature trees are mechanically damaged by a variety of actions, conscious and unconscious, taken by both visitors and managers.

2. Of these impacts, the most serious is probably lack of tree regeneration. Even in the many situations where premature mortality is not a problem, the existing overstory will eventually die. On most campsites, however, there is no regeneration to replace these trees when they die. Most seedlings are killed by being trampled, and the ones that do survive are cut down in the sapling stage for firewood or poles. Finding a way to allow trees to grow into the large-sized classes is one of the major challenges to management of campsites.

3. Vegetation impacts occur rapidly during the initial development and use of recreation sites. Most impacts also reach near-maximum levels of impact even on relatively lightly used sites. This reflects the ground cover vegetation's low level of resistance to trampling damage. Damage to mature trees also occurs rapidly with only light use. However, amount of tree damage is strongly influenced by the type of use that occurs on the site. Stock use, for example, tends to cause more damage than use by parties without stock.

4. Susceptibility to damage also varies greatly between different environments. In this chapter we discussed vegetative characteristics that make a plant resistant to trampling impact. We also discussed how damage to mature trees is more pronounced

for thin-barked trees. Damage also is greater where soils are thin and are prone to erosion and/or drought. A more complete discussion of environmental durability will be provided in Chapter 8.

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