# 8 Environmental Durability

Now that we have developed an understanding of recreational impacts on soil, vegetation, wildlife, and water and the patterns these impacts exhibit in space and over time, we will examine some factors that influence impact patterns. This is critical because it is through manipulation of these factors that managers can control recreational impacts. Many factors affect amount of impact and impact patterns on the land. Certain of these factors relate to environmental characteristics of the sites where recreational use is occurring. Both inherent site conditions and site durability during the season when use occurs can be important. These topics will be the focus of this chapter. Use characteristics, of course, are also highly influential. The importance of various characteristics of use will be the topic of Chapter 9.

Of all the topics in this book, environmental durability is probably the most difficult topic to do justice to in just one chapter; it is an extremely complex subject and one for which there is much suggestive information but few definitive answers. One characteristic may make a site durable while another makes it vulnerable. For example, a meadow may be resistant to vegetation loss, while its soils are highly vulnerable to erosion. There is also an important distinction between the properties of *resistance* and *resilience*. Resistance is the site's ability to tolerate recreational use without changing or being disturbed. It might be quantified in terms of the amount of use a site can absorb before some level of impact is reached. Resilience is the ability to recover from any changes that do occur. It might be quantified in terms of the number of years it takes for a site to recover from some level of impact to its predisturbance condition. Some sites are resistant but not resilient. They can tolerate a substantial amount of use; however, once impact occurs, it lasts for a long time. Many desert and alpine sites provide good examples. Other sites, such as many riparian areas, are resilient but not resistant. They are rapidly impacted, but recovery is also rapid. On sites designated for long-term recreation use, such as developed campgrounds, resilience may be much less important than resistance. Because these sites will be used in perpetuity, recovery is not an issue. In areas of highly dispersed use, however, resilience is at least as important as resistance because management objectives in such places stress the avoidance of permanently impacted sites. Sun and Liddle (1991) compared the trampling response of a resistant grass species to that of a resilient grass. The resistant grass maintained more biomass when trampling occurred throughout the growing season. The resilient grass did better when the trampled plants remained untrampled for a relatively long time. Both resistance and resilience must be considered, and their relative importance varies with management objectives.

Much more is known about the durability of vegetation and soil than about that of wildlife and water. Consequently, most of this chapter will deal with effects on vegetation and soil. Separate sections on wildlife and water are provided near the end of the chapter. It is convenient to group the environmental characteristics that influence vegetation and soil impact into vegetation characteristics, soil characteristics, and topographic characteristics. At a higher level of generalization, it is also possible to describe the importance of ecosystem-level characteristics. Durability is further affected by broad differences in regional climates, but regional climates will not be discussed because they cannot be influenced by management.

## VEGETATIONAL RESISTANCE

Much of a site's durability can be assessed by examining vegetation characteristics. Influential characteristics include the resistance of individual species, species composition of the vegetation, total amount of vegetation cover, and vegetation structure (physiognomy). Characteristics that make individual species resistant were described in Chapter 3.

Attempts to generalize about the relative durability of various groups of plants provide useful guidelines for assessing the durability of different environments. Places where resistant plants are abundant will obviously be more resistant to vegetation loss than places where most plants are fragile. As mentioned earlier, mature trees and graminoids (grasslike plants) are generally resistant; mosses are neither highly resistant nor highly sensitive; and lichens and tree seedlings are highly sensitive. Shrubs are moderately resistant, but their resilience is usually low once they are seriously damaged. Forbs vary from moderately resistant to highly sensitive, but resilience is usually greater than for shrubs. The likely response of forbs, for which variation in resistance between species is high, can be predicted using the list of resistant characteristics in Chapter 3. Erect forbs, growing in moist areas in the forest, are particularly sensitive. Prostrate, low-growing forbs are more resistant.

Despite these general trends, there are numerous exceptions. Even the response of two individual plants within the same species can be variable. Ecotypic differences—genetic differences between individuals that result from adaptations to different environments—can result in pronounced variations in resistance. High elevation ecotypes are often shorter and more matted than their low elevation counterparts; consequently, they are likely to be more resistant (Kuss and Graefe 1985). Other species exhibit important phenotypic differences—differences in form and structure that are not genetically based. Bluegrass, for example, can abandon the erect form it exhibits in undisturbed environments and adopt a prostrate growth form in trampled areas. This increases its ability to tolerate trampling (Burden and Randerson 1972). In Australia, Sun (Sun 1990; Sun and Liddle 1993) showed that trampling resistance of a grass increased with plant age and number of tillers.

The relative resistance of plants also differs between seasons. Many forbs are particularly fragile early in the season when they are growing rapidly; shrubs are often more fragile late in the season, when their dry branches and stems are particularly brittle. The resistance of a species even depends on the other species with which it is associated. Holmes and Dobson (1976), working in subalpine meadows in Yosemite National Park, California, found that survival rates for the same species were generally about three times greater in communities of several species than when it grew in pure stands. Cole (1988) found that sensitive species could tolerate more trampling when growing interspersed with more resistant species. Generally, resistance increases where there are several vegetation layers. Tall layers of plants absorb impact, protecting lower layers. Lower layers provide a cushioning effect that somewhat reduces impact to taller layers.

Many analyses of the relative resistance of entire species assemblages have been made. Commonly a researcher will experimentally trample several different vegetation types and compare responses to see which types decrease in cover most rapidly. Although many studies have examined the initial resistance of vegetation, only a few have followed recovery to evaluate resilience.

The graph in Fig. 1 provides some data from an experimental trampling study undertaken in western Montana (Cole 1985). Two vegetation types are compared. Type 1 is a forest with an understory dominated by lush, erect forbs, species adapted to growth in heavy shade (Fig. 2). Type 2 is a forest with an understory dominated by shrubs that spread along the ground only a few inches off the surface. In each type

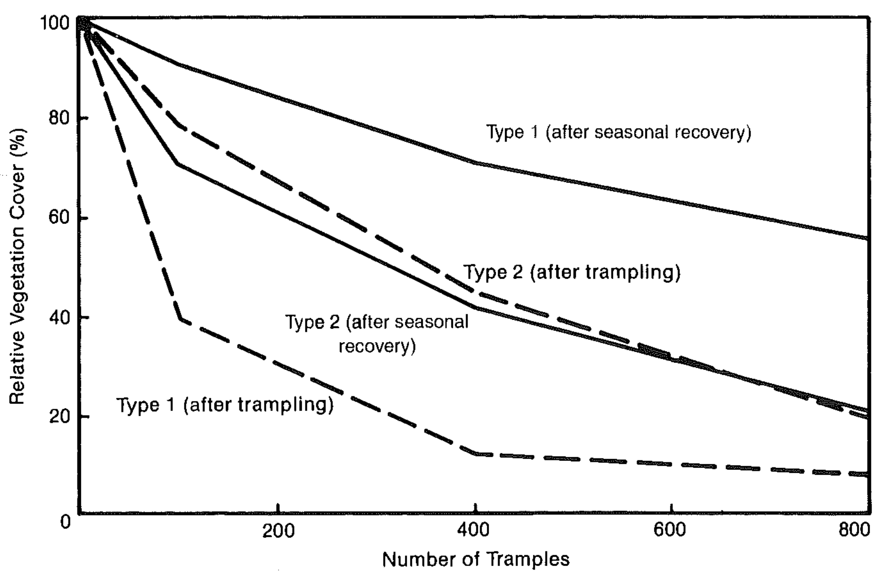


**FIGURE 1.** Relationship between surviving vegetation cover and number of experimental tramples for two vegetation types in western Montana. Type 1 is a forest with a ground cover dominated by lush forbs. Type 2 is a forest dominated by low-lying shrubs. One set of measurements, relevant to evaluating resistance, shows cover after trampling. Another set of measurements, relevant to evaluating resilience, shows cover after an over-winter recovery period. (*Source:* D. N. Cole, 1985.)

**FIGURE 2.** This vegetation type, with an understory dominated by lush forbs, has low resistance and high resilience. (*Photo:* J. L. Marion.)

people walked a given number of times back and forth across the vegetation; each one-way pass was a "trample." The low resistance of the forbs in type 1 is reflected in the "after trampling" graph in which more than one-half of the cover is lost after fewer than 100 tramples. The low shrubs in type 2 are much more resistant; about 300 tramples are required before one-half of the cover is lost. This conforms to our expectations based on the relative resistance of these two growth forms. Although not presented in the graph, a grassland retained over one-half of its cover after 1600 tramples (Cole 1985), illustrating the much greater resistance of graminoids (Fig. 3). At the highest level of trampling reported—800 tramples—the difference in cover between types 1 and 2 is diminishing. Eventually all cover will be lost on even the most resistant vegetation type. The importance of differences in resistance between vegetation types is greatest at low to moderate use intensities. This fact has important management implications. There is little value to worrying about encouraging use of resistant vegetation when use levels are high. Where use levels are low, however, selection of durable sites can be quite effective in minimizing impact.

The two other lines on the graph show vegetation cover on each type in early summer, about nine months after trampling stopped. These data provide some idea about the ability of these vegetation types to recover from trampling. Type 1 recovered well; places that had been trampled 800 times recovered from less than 10 percent cover (after trampling) to more than 50 percent cover over the winter. Although most of the aboveground cover of forbs was destroyed by trampling, the

**FIGURE 3.** Grasslands tend to be particularly resistant to damage from trampling. (*Photo:* M. E. Petersen.)

forbs were able to reproduce or initiate new growth from buds. Recovery was also improved by the abundant moisture in this vegetation type. After a second season of trampling, however, the amount of over-winter recovery in type 1 was greatly reduced. This suggests that resilience declines with successive years of disturbance (Cole 1987).

The high resilience of type 1 is in marked contrast to the low resilience of type 2. Cover in type 2 actually decreased slightly over the winter. Delayed trampling damage is common in shrubs, particularly ericaceous heaths and huckleberries (Bayfield 1979; Cole 1995b). Stems and branches of the shrubs apparently were damaged during trampling but continued to provide cover until winter when they fell off. Very little regrowth or reproduction occurred over winter to offset this loss of cover.

Cole (1995a, 1995b) has conducted the most extensive experimental trampling study to date. He studied 18 different vegetation types, distributed over wide elevational ranges in five separate mountain regions in the United States—in Washington, Montana, Colorado, New Hampshire and North Carolina. He found tremendous variation in response to trampling—at least a 30-fold difference in resistance. In an alpine sedge meadow in Washington, it took 600 "tramples" to eliminate 50 percent of the vegetation cover. It took just 20 tramples in a spruce-fir forest with a fern-dominated understory, in Great Smoky Mountains National Park, to eliminate 50 percent of the vegetation cover. In many places, particularly subalpine ecosystems—where the diversity of vegetation types with different growth forms is unusually high—vegetation types that differ in resistance by a factor of 10 or more grow interspersed with each other. This suggests that there is great potential to reduce impact by channeling use through more resistant vegetation types.

As noted earlier, many researchers have suggested that vegetation resistance to trampling is largely a function of the growth form of constituent species. Cole (1995b) was able to verify this hypothesis empirically. In the 18 vegetation types he studied, resistance to trampling was positively related to the abundance of graminoids (particularly tufted grasses and sedges) and shrubs; it was negatively related to mean vegetation height and the abundance of erect plants (particularly forbs). Sixty-eight percent of the variation in resistance of individual species could be predicted simply by noting whether they were shrubs, forbs, or grasslike plants. Graminoids were resistant, forbs were sensitive, and shrubs were intermediate in response (Fig. 4). There are exceptions to this generalization, of course. Nevertheless, the simplicity of this finding suggests that it may be reasonable to teach recreationists to recognize resistant and sensitive vegetation types.

Resilience was also strongly affected by growth form. In the 18 vegetation types, resilience to trampling was positively related to the abundance of forbs and negatively related to the abundance of shrubs. Plants with regenerating buds located above the ground surface—all shrubs and a few other plants—recover very slowly once disturbed. The buds themselves are often destroyed by trampling, and woody plant tissues typically grow more slowly than herbaceous tissues. Resilience also declined with elevation, although the effect of elevation was minor as compared with the effect of growth form. It has been suggested that—as compared with resistance—resilience

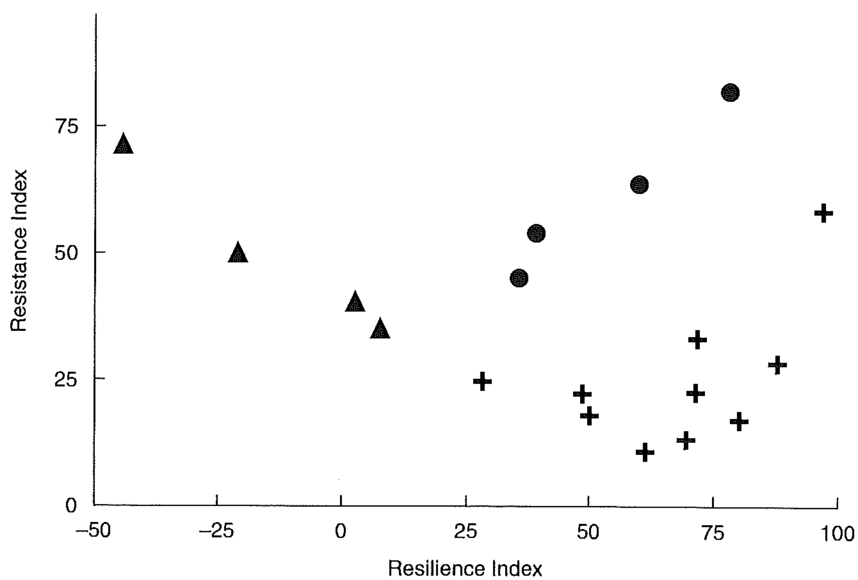


**FIGURE 4.** Resistance and resilience of 18 vegetation types with understory vegetation dominated by shrubs (▲), graminoids (●), or forbs (+). (*Source:* Adapted from data presented in Cole 1995b.)

should be more strongly influenced by a number of environmental variables such as soil fertility, length of the growing season, sunlight levels, and moisture levels (Cole 1988). The importance of these factors will be discussed later in more detail.

The effect of amount of vegetation cover on durability is complex. Both sparsely and densely vegetated plant communities can be highly resistant; both can also be fragile. Cole (1995b) found a positive relationship—in the 18 vegetation types he studied—between resistance to trampling and total vegetation cover. It may be that plants growing in a dense turf are less susceptible to being uprooted by the gouging actions of feet. Perhaps the most important effect of vegetation cover is its ability to inhibit erosion. Vegetation acts to hold soil in place and reduce the erosive force of running water. Vegetation types that can retain a dense vegetation cover, despite being subjected to trampling, will resist damage from erosion more effectively than other types. Types with abundant graminoids and/or exotic, trampling-resistant species are particularly likely to retain a dense cover, as are highly resilient vegetation types.

The most significant aspect of vegetation structure is the effect of tree canopy closure on vegetation loss. As we have noted before, plants that grow in heavy shade tend to be more fragile than those that inhabit more open communities. This is well illustrated in Table 1, which shows vegetation cover and loss on campsites in the Boundary Waters Canoe Area in relation to canopy cover. Mean cover is the mean vegetation cover on campsites. Absolute difference is an estimate of the vegetation loss that has occurred as a result of campsite use. It is obtained by calculating the difference in cover between campsites and neighboring undisturbed control sites. Both measures show much greater impact where tree cover exceeds 25 percent. Impact increases with each increase in tree cover; very little cover (only 3.5 percent) survives on the most shaded sites. In his trampling study, Cole (1995b) found that tree canopy cover was the variable that explained most of the variation in resistance to trampling. The effect of canopy cover is primarily indirect, however. Canopy cover influences plant growth form because certain growth forms grow better than others under closed canopies; growth form, in turn, determines resistance to trampling.

**TABLE 1. Relationship Between Tree Canopy Cover and Vegetation Cover on Campsites in the Boundary Waters Canoe Area, Minnesota**

| | Vegetation Cover (%) | |
|---|---|---|
| Tree Cover (%) | Mean[a] | Absolute Difference[b] |
| 0–25 | 52.4 | –43.6 |
| 26–50 | 25.8 | –60.7 |
| 51–75 | 14.9 | –70.3 |
| 76–100 | 3.5 | –77.1 |

*Source:* Marion 1984.

[a]Means are for surviving vegetation cover on campsites.

[b]Absolute difference is the difference in cover between campsites and undisturbed control sites—an estimate of vegetation loss.

## SOIL CHARACTERISTICS

Soil characteristics that have a pronounced effect on durability include soil texture, stoniness, organic matter, moisture, fertility, and depth. The soil textures with the fewest limitations for campsites and trails are medium-textured soils—sandy loams, fine sandy loams, and loams. Such soils usually have good drainage, are not highly erodible, and have a high potential for plant growth. Their major drawback is that their wide range of particle sizes makes them particularly susceptible to compaction. Coarse soils generally resist water and wind erosion because large particles are not easily moved by wind or water. However, structural instability makes coarse soils vulnerable to trail widening, and their low water-holding capacity and cation exchange capacity (ability to hold cations that may be important nutrients) make them relatively impoverished environments for plant growth. Such drawbacks are likely to be more serious for trails than for campsites. In remote backcountry situations where use is low and dispersed, sandy soils may be particularly resistant sites for camping.

Coarse soils are clearly a better alternative than fine-textured soils. Silts and fine sands are highly erodible because soil particles are both readily detached and moved, the two requisites for erosion to occur. Moreover, silt is particularly prone to the formation of needle ice and to frost heaving, processes that increase erosion and make revegetation of bare areas difficult. Silt soils also become dusty when dry, making them undesirable trail locations. The permeability is greatly reduced when clay soil is compacted. This promotes increased runoff and erosion. Although clay particles resist detachment, they are readily moved by running water. Clays have a limited ability to support loads because they deform readily when wet. They also tend to be sticky when wet, and they dry slowly (Leeson 1979). All of these characteristics make clay soils particularly poor locations for recreational facilities.

The effect of stones and rocks on soil durability is variable. Leeson (1979) suggests, based on studies of trails in the Canadian Rockies, that it is advantageous for stones and rocks to comprise up to 25 percent of a soil's volume. Small amounts of stone in the soil reduce susceptibility to compaction (Stewart and Cameron 1992). Stones also increase the resistance of soil particles to being picked up by moving water. Above 25 percent, however, stones and rocks make footing difficult and construction and maintenance costly. Once stones are loose on the trail, they increase the turbulence of running water (increasing erosion) and erode the trail themselves when tumbled down the trail by water. Summer (1980) suggests not categorically removing all stones from trails because this sets up a never-ending cycle of deterioration. Removal of rocks leads to exposure and erosion of underlying fine particles, which, once they are removed, exposes more rocks at the surface.

Many of the most serious trail problems occur where soils are stone-free and homogeneous in texture. Such soils, which frequently occur in mountain meadows, are highly vulnerable to erosion (Bryan 1977). Deep and narrow seasonally muddy trails force hikers and stock out of the rutted, muddy trails. New ruts develop alongside the old ones, quickly scarring scenic meadows with numerous parallel ruts (Fig. 5).

**FIGURE 5.** Multiple trails are developing in this meadow. The main tread is deep, muddy, and wet, making it difficult to use. Hikers prefer to leave the tread, creating new parallel trails. (*Photo:* R. F. Washburne.)

The advantages and disadvantages of organic matter are also complex, varying with amount and type of organic matter and with associated soil characteristics. Organic soils, those in which organic content exceeds 20 to 30 percent, are the soils least capable of supporting recreation use. They tend to occur where drainage is or has been poor; they are particularly common at high elevations and latitudes where decomposition of organic matter is slow. Such soils have little ability to support heavy loads, particularly when they are wet. Recreational use of areas with organic soils rapidly creates wide, muddy quagmires. However, a thick organic horizon on top of mineral soil tends to shield the mineral soil from compaction and inhibits runoff and erosion. Incorporated into the mineral soil, organic matter promotes good structural development, which enhances drainage, inhibits compaction, helps resist dispersion and detachment of particles, and promotes plant growth because of its tendency to increase water-holding capacity and nutrient availability.

Soil moisture, as with most soil parameters, is most advantageous in moderate quantities, where it is sufficient to promote plant growth and recovery but not so abundant that it causes the problems common to poorly drained, wet soils. Soils with excessive moisture cannot bear loads without becoming muddy and greatly compacted. Wet soils are more susceptible to truncation because of their increased stickiness and adhesion to footwear of hikers (Stewart and Cameron 1992). Moisture problems are most serious in fine-textured soils and are most likely to cause problems on trails. Such problems are particularly severe where stock use is heavy because of the great pressure stock exert on the soil. The majority of trail problems, other than erosion on steep slopes, result from locating trails in areas that are poorly drained or that have high water tables (Cole 1991).

Limited data suggest that the vegetation on moderately fertile soils is more resistant to impact than that on either highly fertile soils or infertile soils (Harrison 1981; Kuss 1986). There are insufficient data, however, to evaluate whether or not these results are generally applicable. Certainly the resilience of more fertile sites should be greater than that of sites poor in nutrients.

Finally, deep soils are often better suited to recreational use than shallow soils. This primarily reflects the high erodibility of very shallow soils and the vulnerability of vegetation established in pockets of thin soil. Another concern relates to the difficulty of disposing of human waste in environments where soils are shallow. On the other hand, some of the most resistant sites for low-use, dispersed backcountry camping are on bedrock, where the impacts of recreation use are likely to be minimal.

Table 2 summarizes, in very general terms, how soil properties influence site durability. As the preceding discussion suggests, there are exceptions to most of these generalizations. Still, they do provide some useful guidelines for locating facilities such as trails and campsites. The most serious and widespread problems occur where trails are located on soils with homogeneous textures (the usual problem is creation of a system of deeply incised, braided trails in meadows) or where any facility is located on wet mineral or organic soils (the usual problem is creation of a wide and muddy quagmire).

Soil maps can be a helpful means of incorporating knowledge about soil durability into recreation impact management. For example, Bailey and Pilgrim (1983) mapped the soils of the White Mountains in New Hampshire. Then they developed a table listing the suitability of these different soil types for different recreation uses. The soils most suitable for dispersed camping and trails were typic Haplorthods developed on friable till, at elevations below about 2500 feet and on slopes of less than 15 percent. This analysis provides only a very coarse perspective on facility location, however. Field observations and concern for a broader array of soil criteria are needed for more precise locational decisions.

**TABLE 2. Relationships Between Soil Characteristics and Susceptibility to Impact**

| | Level of Susceptibility | | |
|---|---|---|---|
| Soil Property | Low | Moderate | High |
| Texture | Medium | Coarse | Homogeneous; fine |
| Stoniness | Moderate | High | Low |
| Organic context | Moderate | Low | High |
| Soil moisture | Moderate | Low | High |
| Fertility | Moderate | High | Low |
| Soil depth | None | Deep | Shallow |

## TOPOGRAPHIC CHARACTERISTICS

Durability is often related to slope steepness and position, topography, elevation, and aspect. Slope steepness and position are most important in influencing impacts on trails and roads or in places where cross-country travel occurs regularly. Generally, erosion potential increases with slope. For example, Coleman (1981) studied the prevalence of erosion problems on trail segments of variable slope. On trails with a slope no greater than 9 degrees, erosion problems were nonexistent; between 9 and 18 degrees erosion problems occurred, but most segments were not eroding; above 18 degrees most trails were eroding (Fig. 6). She also found that both trail width and depth increased as the slope of the trail increased. The increase in trail depth with slope reflects greater erosion caused by the increased velocity of water running down steeper trails. In Alaska, Jubenville and O'Sullivan (1987) found a positive relationship between slope gradient and trail erosion; however, gradient explained only 34 percent of the variance, suggesting that other determinants of erosion are important. The increase in width may result from either people walking on the sides of deeply eroded, steep trails to get better footing or the tendency for people to spread out

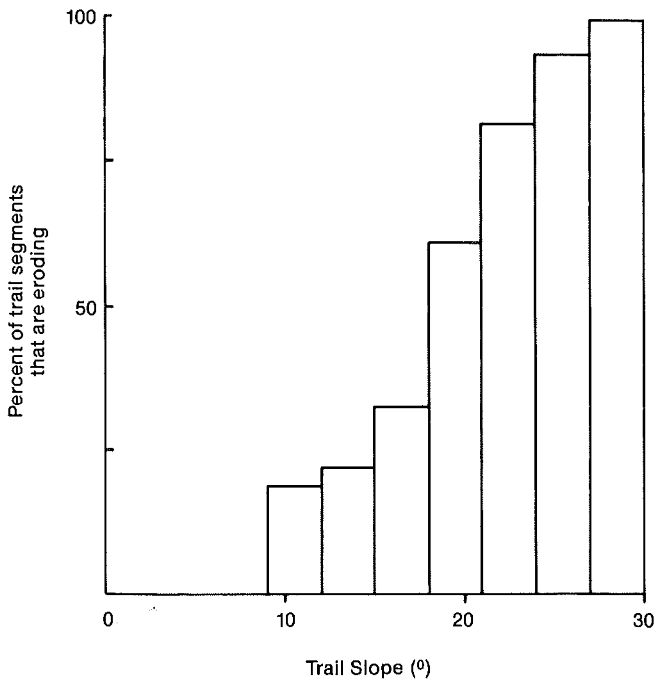


**FIGURE 6.** The frequency of erosion problems tends to increase as trail slope increases. Data are from footpaths in the Lake District of England. (*Source:* Adapted from Coleman, R. "Footpath Erosion in the English Lake District," in *Applied Geography.* Copyright © 1981. Used with permission of the publisher.)

laterally when negotiating a steep slope. In Great Smoky Mountains National Park, Marion (1994) also found that trails with steep slopes were substantially wider than those that were less steep.

Where steep slopes cannot be avoided, problems can frequently be averted by putting in water drainage devices such as drainage dips and water bars (see Chapter 13). Problems also occur on trail segments where there is no slope at all. Trail segments without any slope drain poorly. Poor drainage leads to the development of muddy quagmires that expand in width as hikers and stock try to skirt the mud. Campsites with poor drainage are undesirable when wet. Campers who do use such areas often end up excavating trenches around their tents when rainfall is intense. Such impact can be avoided by locating sites where there is some slope and drainage.

Trails and roads located high on slopes have smaller watersheds from which they collect water than those located close to the base of slopes. This smaller watershed reduces erosion potential. However, trails on upper slopes are often unusually wide (Leung and Marion 1996). Locations close to the base of slopes can also have problems with excessive moisture because springs may be intercepted by roads or trails cut into the slope (Cole 1983; Marion 1994). Midslope positions are usually the best choice.

A more significant variable than slope position is the alignment of a trail in relation to the prevailing slope. Trails that directly ascend the fall line are susceptible to degradation regardless of slope angle. Flat sideslopes offer little hindrance to trail widening, and trail drainage can be a problem. Trails that more closely follow contours are less problematic. Drainage is better and hikers are more likely to stay on the constructed trail. The importance of trail alignment increases as trail slope increases (Leung and Marion 1996).

Variable results are available concerning the effect of elevation on site durability. In the Great Smoky Mountains National park, Bratton, Hickler, and Graves (1979) report that both trail and campsite deterioration increase with elevation. This has been confirmed by more recent trail surveys in the Smoky Mountains (Marion 1994). Higher rainfall and thinner soils occur at the higher elevations, contributing to more pronounced erosion and other soil impacts. Deterioration problems are also reported to be more severe at high elevations in the northeastern United States (Fay, Rice, and Berg 1977). In the Sierra Nevada in California, campsite alteration was greater at both high and low elevations than at moderate elevations (Dykema 1971). As noted earlier, Cole (1995b) found that vegetation resistance declined with increasing elevation, but the effect was miniscule in comparison to the effect of plant growth form.

The complexity of factors influencing environmental tolerance makes it unlikely for a variable like elevation to relate strongly to durability. Perhaps the most important effect of increasing elevation is a decrease in length of the growing season. This, along with locally variable factors such as frequent high winds and needle ice, often make resilience low at high elevations. Depending on the growth forms present, high elevation vegetation can be either resistant or fragile; however, because of the short growing season it will always recover slowly from any damage that occurs. In desert regions, higher elevations receive more precipitation, which is likely to increase resilience. If the increase in resilience because of higher moisture levels compensates for the decreases in resilience related to a shorter growing season, then even resilience will increase with elevation.

Within a local area it may be possible to identify a relationship between the incidence of impact problems and elevation. This is what Bratton and her colleagues (1979) did for trails and campsites in the Great Smoky Mountains. However, such relationships are unlikely to be broadly applicable. Moreover, the effect of elevation on resistance may be different from its effect on resilience. Effects are also likely to differ between vegetation, soil, wildlife, and water and between types of facilities and activities. Guidelines relating elevation to durability, although useful, should be used cautiously.

The same is true for aspect. North-facing aspects may be more durable in one place and more fragile in another. One of the most common aspect-related problems occurs high in the mountains, where late snowmelt on north-facing aspects keeps soils water-saturated. Trails through water-saturated soils become wide, muddy quagmires. They are also eroded by meltwater, channeled down the entrenched trail. Under droughty, low elevation conditions, however, north-facing aspects may be particularly resilient because of higher moisture levels that promote plant growth. In Iowa, Dawson, Hinz, and Gordon (1974) found that trails on north-facing slopes were less compacted and had lost less ground cover than trails on floodplains or south-facing slopes. As with elevation, such generalizations can be useful within localized areas, but they have little general utility.

## ECOSYSTEM CHARACTERISTICS

Some researchers have proposed that vegetation durability increases with increases in an ecosystem's primary productivity (Liddle 1975) and is greater in more advanced successional stages (Goldsmith 1974). Primary productivity refers to the quantity of organic matter produced by plants through photosynthesis. It is dependent on many factors, from broad climatic characteristics such as temperature and rainfall, to soil characteristics such as nutrient availability. Liddle believed that productivity summarized, in one measure, potential for regrowth as well as the general ability of the environment to support growth. Resilience probably is strongly related to productivity. For example, campsites in productive riparian forests in the eastern United States recovered substantially in just six years (Marion and Cole 1996). Trails in Costa Rican rain forest recovered dramatically in 32 months (Boucher, Aviles, Chepote, Gil, and Vilchez 1991). Resistance is not strongly related to productivity, however. For example, desert shrubs are resistant, despite their not being highly productive. A moisture rich, temperate forest is productive, but the vegetation is quickly eliminated by trampling. As we have seen before, resilience is related to general environmental factors, but vegetation resistance is dependent primarily on the growth forms of constituent species.

Communities and ecosystems change with time. Succession is the relatively orderly change from young, simple ecosystems to more diverse and specialized older ecosystems. The more advanced stages of succession may be more resilient because their higher productivity, diversity, and higher degree of specialization promote more rapid recovery following damage. However, resistance is not so clearly related to successional stage. Some early successional stages such as grassy fields and dry meadows are much more resistant than the later forested stage of succession. Trails in mature forest in the Great Smoky Mountains were more substantially impacted then trails in early successional forest (Bratton, Hickler, and Graves 1979). Again, growth form probably has more influence on vegetation resistance than successional stage, and individual soil characteristics such as texture have more influence on soil resistance.

There is no doubt that environmental factors profoundly influence amount of impact. The problem is that so many of the relationships between environment and impact are highly site specific. Relationships that apply in one place may not apply in another. In this chapter we have described some of the factors that are likely to influence durability. Ultimately, each area will have to develop its own guidelines for where to develop facilities. A good example is provided in Table 3. These guidelines specify likely problems in different vegetation types in the mountains of New England. They were developed over the years by observing where certain problems generally occur. They are useful in New England, although they may not apply elsewhere.

## WILDLIFE IMPACTS

Much was said about the vulnerability of different wildlife species in Chapter 4. For a given species, susceptibility also varies among different environments. Unfortunately, very little work has been done on this subject. Therefore, all we will be able to do here is present some relatively simple principles. Vulnerability to disturbance is usually greatest at certain key locations, particularly breeding areas, feeding areas, and watering holes. Disturbance of nesting birds has caused adults to fly off, leaving eggs and hatchlings open to predation (Burger 1995). Severe or prolonged disturbance can lead to nest abandonment. Prolonged disturbance of animals in prime feeding and water areas can force them to use poor habitat. In one study deer displaced to poor habitat had lower reproductive rates and less body fat. Moreover, they did not return to the better habitat even after disturbance had stopped (Batcheler 1968). Such disturbances can be particularly damaging to wildlife populations during periods of harsh weather or during unproductive years. Generally, sensitive environments are those key locations where the consequences of disturbance, flight, or displacement are particularly detrimental. Exactly which environments these are will vary between species, but certain habitats such as riparian areas are almost always critical for many species.

Wildlife are often more adversely affected when approached from above. Hikers approaching bighorn sheep from upslope caused stronger reactions than those approaching from downslope, presumably because sheep perceive less ability to escape when upslope escape options are eliminated (Geist, Stemp, and Johnston 1985).

**TABLE 3. Vegetation Type and Plant Tolerance to Dispersed Recreation Impacts in New England Mountains**

| Vegetation | Conditions to Which Vegetation Is Intolerant |
|---|---|
| Alpine plants | Trampling easily destroys these fragile plants. Due to the short growing season and other harsh conditions, alpine plants are very slow to regenerate |
| Subalpine bog plants; sphagnum moss, sedges, dwarfed heath shrubs | Roots of bog plants are easily crushed by foot traffic, though some species are adapted to colonizing disturbed denuded soils. |
| Krummholz | These trees are very slow growing. Clearing for tent sites rapidly destroys the krummholz and exposes them to wind damage. |
| Spruce-fir forests | Susceptible to windthrow where large openings have been cut. Compaction of soil around roots reduces tree vigor by reducing water and air infiltration and increasing their susceptibility to disease. Basal wounds make trees susceptible to fungal infections. |
| Mixed beech, sugar maple, birch forest | Can sustain a moderate amount of soil compaction and bark wounding. |
| Red maple trees | Can sustain a moderate amount of soil compaction and bark wounding. |
| Pure yellow or paper birch stands | Trees subject to bark peeling and cutting for firewood. This becomes visually unesthetic and also reduces the vigor of the trees by increasing their susceptibility to disease. Openings cut in stands cause trees near opening edges to be subject to wind damage and dieback. |
| Pines, oaks, rhododendrons | Moderately durable vegetation. |
| Alders, willows | Moderately durable vegetation, though sites are generally unattractive to camping due to moist conditions. |

*Source:* Adapted from Leonard, Spencer, and Plumley, 1981. Copyright © 1981 by Appalachian Mountain Club, used with permission of publisher.

## WATER IMPACTS

As in the case of wildlife impacts, there is little research on the susceptibility of different aquatic environments to recreation-related water impacts. Obviously, recreational activities undertaken in or near water have more potential for causing water pollution than those occurring far from water. On-land recreational activities are also more likely to adversely alter water quality where soils are highly erodible. For example, building roads and trails through areas of highly erosive material can greatly increase water turbidity, a change with negative effects on aquatic flora and fauna.

Water bodies themselves also differ in their ability to tolerate impact. Those that are frequently flushed out by large quantities of water or that have chemical properties that can buffer pollutants are less vulnerable to impacts than those without these properties. Lakes at high elevations commonly have low temperatures, few nutrients, and low levels of productivity. They often are in pristine areas where baseline disturbance levels are low. Recreational use on or around such lakes can cause pronounced deviations in biological, chemical, and physical properties from those found under baseline conditions. Lakes and streams at lower elevations tend to be more productive and less vulnerable to alteration than alpine lakes.

## SEASON OF USE

The durability of an environment varies substantially between seasons. Vegetation and soil, for example, are protected from impact, to a great extent, when there is a thick blanket of winter snow. They may be particularly vulnerable in spring, however, when soils are saturated with snowmelt or spring rains. Young, tender herbaceous plants are particularly susceptible to trampling in the spring, causing early season loss of photosynthetic tissues, which means that plants must go an entire season without adding to their food reserves.

Season of use can be influential in determining the vulnerability of certain wildlife species and of water quality. Recreational activities have traditionally been considered particularly disturbing to animals during the breeding season. However, recent research indicates that disturbance during other seasons can be equally detrimental (Hobbs 1989; Skagen, Knight, and Orians 1991). The consequences of disturbance during different seasons are variable. During breeding season, disturbance affects productivity. During other seasons it affects fitness and survival. Animals are particularly vulnerable to disturbance during times of the year when they are weak. A number of animals, including deer, adapt to severe winter conditions by decreasing their level of activity and, thereby, conserving their energy. If encounters with recreationists cause them to flee, this strategy is undermined. Increased activity requires more food; if sufficient food is not available, it can lead to reduced vigor and reproductive capacity or even death. Hobbs (1989) suggests that the effect of disturbance on food intake is more detrimental than its effect on energy expenditure. Harassment of wildlife species during winter months, when they are under physiological stress, is one of the most serious impact problems associated with snow recreation on skis or snowmobiles. Although winter is the season when the vulnerability of soil and vegetation is generally lowest, it may be the season when wildlife vulnerability is highest (Fig. 7).

Water quality is most likely to be adversely affected if recreation use occurs during the season when soils are saturated with water from snowmelt. Vehicular travel on roads during this period can cause serious erosion, because vehicles churn up the soil to the point where it can be easily moved by running water. Serious erosion of roads increases

**FIGURE 7.** Wildlife disturbance can be particularly detrimental during winter when movement requires large amounts of energy and animals have little energy to spare. (*Photo:* R. C. Lucas.)

road maintenance costs; it also increases siltation of streams. This can have numerous adverse impacts, particularly on fish such as trout, that are sensitive to stream turbidity.

Vulnerability also varies greatly between seasons where there is erosion of trails and trampling damage to meadows used by recreational packstock. In both cases, problems are most severe during the spring when snowmelt and spring rains keep soils saturated. The trail erosion problems are similar to the road erosion problems caused by motorized use. Wet soils are easily broken up, making them sensitive to movement where snowmelt is channeled down the trail. Trail use, particularly by stock, should be discouraged during snowmelt. Drainage devices, to divert water off the tread, are also important if severe erosion is to be avoided.

Meadow soil and vegetation can be rapidly disturbed when trampled during spring when soils are wet. Wet soils are more prone to compaction and more readily churned. This breaks up the meadow sod into a honeycombed topography, leading to both an increase in erosion and a lowering of the water table. In Sequoia and Kings Canyon National Parks, meadows dried out as water tables dropped, and this permitted trees to invade and replace meadows (DeBenedetti and Parsons 1979).

Vegetational tolerance varies between seasons, but differences are usually not very pronounced. Resistance of plants to trampling damage is often low during early spring when many herbs are succulent and during late season when plant parts are dry and brittle. However, resilience may be reduced more dramatically by trampling early in the season when perennial plants are still utilizing carbohydrate reserves for growth and before annual plants have had a chance to produce viable seeds. Strand

(1979) showed that the vegetation damage inflicted by horse trampling was greater and lasted longer in a wet meadow than in a dry meadow.

In the mountains, spring is usually the most vulnerable season; soil moisture levels are high and many wildlife species are breeding, as well as recovering from the stresses of winter. Winter is a season of low vulnerability, except for impact to certain wildlife species. The summer season of maximum recreation use is generally intermediate in terms of susceptibility to impact. These general guidelines break down, however, when applied to coastal areas, deserts, areas that do not receive snowfall, and areas that receive intense summer rainfall. In such places the seasons of highest vulnerability are most often those when soils are frequently water saturated and when the consequences of wildlife disturbance are particularly severe.

## SUMMARY

1. The list of properties that either enhance or detract from site durability is long. Only a few of the important ones have been discussed in the preceding sections. Understanding differences in site durability is critical to any impact management program, because locating facilities appropriately and encouraging use of durable sites are important means of limiting impact. Patterns of differential tolerance are highly site specific, however. Specific guidelines on site durability will have to be developed for each individual recreation area (although much information can be borrowed from other areas in similar environments).

2. Field judgments by experienced people, capable of incorporating a wide array of influential factors, are the best means to judge durability. Alternatively, it is possible to develop guidelines that can be used by less experienced evaluators. For example, Garland (1990) developed an index of trail erosion susceptibility for a proposed wilderness area in the Natal Drakensberg, South Africa. The index was based on (1) the amount of rain falling on the wettest day of the year, (2) rock type, and (3) slope. The index has possible scores between 3 and 13. Trails built on sites with index values of 3 are likely to require little maintenance. Trails built on sites with ratings of 4 to 6 are likely to experience little erosion, but a few places may require frequent maintenance. Where sites have ratings greater than 6, maintenance is likely to be frequently necessary and erosion risk is high. In Shenandoah National Park, Williams and Marion (1995) developed an index of the desirability of alternative campsite locations to help managers attempting to identify locations for designated campsites. This index combines both social and environmental durability criteria. It includes (1) location in relation to trails and other campsites, (2) slope, (3) vegetation composition and cover, (4) forest canopy, (5) aspect, and (6) campsite expansion potential—the surface roughness and vegetation density of adjacent areas.

3. Another technique that is useful in deciding where to build facilities or encourage use is to map locations that are particularly sensitive. A series of overlays of sensitive areas and attractions can identify both desirable and undesirable locations. Figure 8 shows maps of some of the factors to be considered when locating campsites

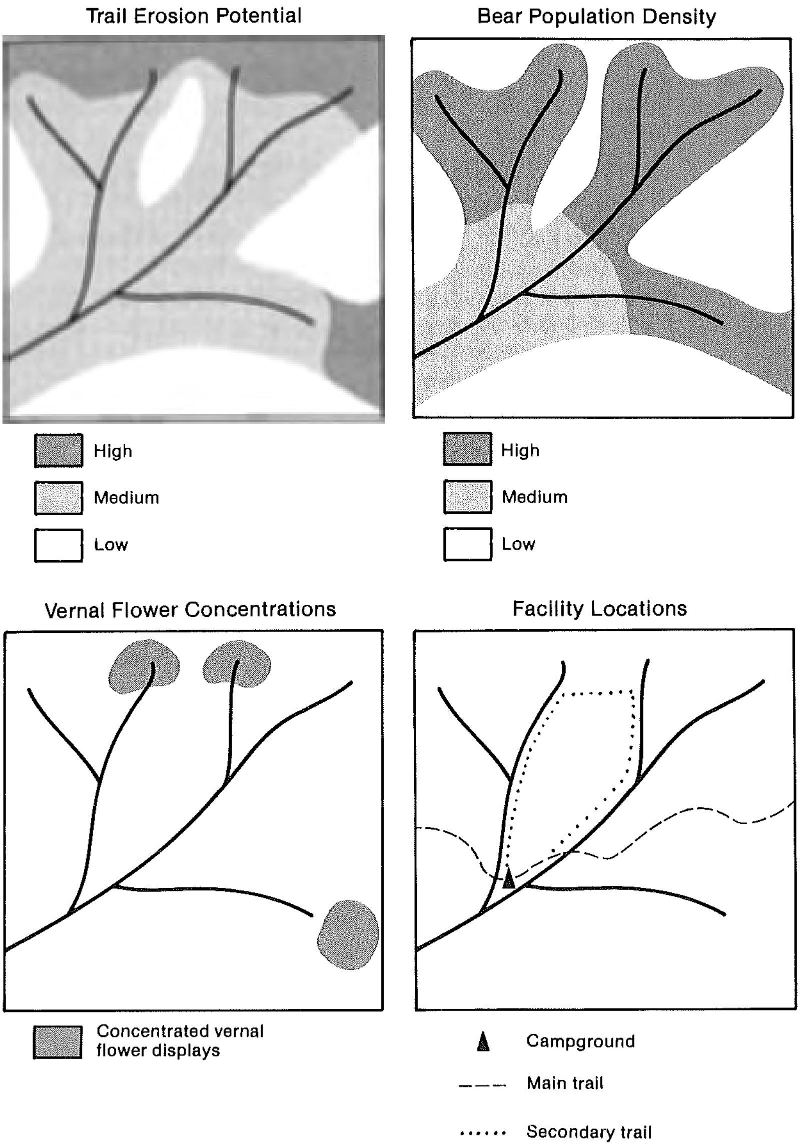


**FIGURE 8.** Maps of environmental factors that influence the placement of trails and campsites in Great Smoky Mountains National Park. (*Source:* Modified from Bratton 1977.)

in Great Smoky Mountains National Park. The campground was located away from places with high bear densities and flower concentrations, but close to water. The main trail stayed in areas with low erosion potential, except where it descended to the campground. Secondary trails were built up to the areas of flower concentrations but attempted to avoid areas where erosion potential was high.

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