4

Impacts of Hiking and Camping on Soils and Vegetation: a Review

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Introduction

Ecotourism affects local environments in many ways. Although some of the most dramatic environmental changes result from development of the infrastructure to support tourism, more widespread impacts result from the recreational activities that tourists engage in. For ecotourists engaged in adventurous pursuits, hiking and camping are perhaps the most common activities that can have profound ecological impacts. This is particularly true in more remote places, protected as parks or wilderness.

Of the many environmental effects of hiking and camping, impacts on soil and vegetation have been most thoroughly explored. Consequently, the literature on this subject is voluminous and is a challenge to review thoroughly. The strategy of this chapter is to provide an historical context for the development of this literature, discuss the types of studies that have been employed (each with inherent strengths and weaknesses) and briefly assess the geographical distribution of research. Emphasis is placed on development of generalities from the literature and identification of critical knowledge gaps, rather than a comprehensive review of many site- and context-specific descriptive studies. I try to identify the early papers that provided the genesis of ideas and concepts, as well as recent papers that extend earlier work conceptually and geographically. Inevitably I have drawn more examples from my own work than might be representative because I am most familiar with their details. Additional sources can be found in several textbooks (Liddle, 1997; Hammitt and Cole, 1998; Newsome *et al.*, 2002) and reviews of the literature (Cole, 1987, 2002; Leung and Marion, 2000).

In this chapter, I do not distinguish between recreation and tourism. From the point of view of impacts to soils and vegetation, differences between the two seem negligible. Ecotourism suggests environments characterized by near-natural conditions, low levels of development and crowding. Fortuitously, most of the literature on recreation impacts has been conducted in such environments, making application to ecotourism straightforward.

Hiking and Camping as Activities

Humans have walked and camped for as long as they have existed. Only in recent centuries, particularly in developed countries, has there been little need for large portions of the population to walk from place to place. In the past half century, this trend has reversed. As the proportion of people with substantial leisure time has increased, people are turning to hiking and camping as recreational activities (Fig. 4.1). In the USA, for example, two-thirds of the population engages in walking for pleasure and

Fig. 4.1. Recreational hiking and backpacking have increased dramatically in the past few decades.

about one-quarter hikes and camps (Cordell and Super, 2000). Increased interest in ecotourism reflects this trend and its dissemination around the globe.

Hiking has always been more ubiquitous than camping, particularly in more developed and less remote places. In road-accessible places, with well-developed infrastructure, most hiking may occur on highly engineered trails designed to absorb the impacts of hiking and to confine those impacts to the designed trail system and nodes of activity (e.g. viewpoints, picnic sites, etc.). Most hiking is of short duration, less than 1 day and often for just an hour or two, with tourists staying the night in some sort of lodging. In addition to staying in overnight lodging, many people camp in road-accessible developed campgrounds, which ideally are designed to confine traffic to surfaces that are hardened to absorb use. In these situations, impacts to soils and vegetation can be limited despite very high visitation levels. Where people venture off the trail system, however, impacts can be pronounced.

Less-developed and more remote areas are used in more variable ways. Day hiking on engineered trails still occurs, but overnight hiking on less-developed trails and even off-trail travel also occurs. In certain parts of the world (e.g. much of Europe, Nepal and New Zealand), long-distance trekkers usually overnight in lodges or shelters, but, in many places, the tradition involves overnight camping. Camping may occur on designated campsites; informal, long-established sites; and even on places that have never been camped on before.

The value of research on recreation impacts to soils and vegetation seems generally greater in less-developed and more remote lands. This has nothing to do with the relative amount or importance of recreation in these places. In less-developed and more remote places, management is more complex, and the knowledge required to manage effectively is greater. Management relies less on engineering and on separating the natural environment from recreational use. Therefore, it is more critical to understand the inherent durability of the natural environment, and how much of what types of use the environment can support. The standards for acceptable levels of impact are also likely to be more stringent, and concern about the obtrusiveness of management is likely to be greater. This management complexity, I think, explains the fact that although most visitation occurs on more developed lands, most research has been conducted in less-developed parks and wilderness areas.

Historical Context of Research

Research on the ecological impacts of recreation has a short history. Although there were a few isolated early studies of the ecological impacts of tourists (Meinecke, 1928) and of vegetation subjected to trampling (Bates, 1935), the 1960s was the decade when interest in recreation impacts first developed widely. Not coincidentally, it was the 1960s when the demand for outdoor recreation first exploded in much of the developed world. This earliest work was descriptive, highly site-specific, seldom published, and largely confined to the USA and western Europe. Few researchers ever conducted more than one study.

By the early 1970s, interest had grown enough for collaborative and cumulative research to be supported. The term 'recreation ecology', the most common descriptor of research on the environmental effects of recreation, was probably coined about this time. By 1973, in Great Britain, the Recreation Ecology Research Group was convening regularly to share information. The first pioneers in recreation ecology also began work in the early 1970s. Neil Bayfield (1971, 1973, 1979) developed the first sustained programme of recreation ecology research, a 20-year programme of government-funded work on trampling and footpath impacts in the mountains of Scotland and England. He was among the first to propose methods for monitoring trail impacts and to investigate means of restoring damaged recreation sites. Michael Liddle began a lifetime of work in academia on recreation impacts, first in Great Britain (Liddle and Greig-Smith, 1975) and later in Australia (Liddle and Kay, 1987). Notably, Liddle (1975a,b) was among the first to search for generalities about recreation impacts and his career culminated in a comprehensive textbook on recreation ecology (Liddle, 1997).

The earliest students of recreation ecology in the USA did not pursue careers in the field. Nevertheless, their contributions were vital. Al Wagar conducted the first simulated trampling experiments, and provided initial conceptual development of the carrying capacity concept (Wagar, 1964). Sid Frissell conducted the first study of campsites that received differing levels of use (Frissell and Duncan, 1965). This research showed that impact occurs wherever use occurs, leading Frissell to suggest that the decision facing recreation managers is how much impact is acceptable – not whether or not to allow impact. This observation provided the conceptual foundation for planning processes such as the Limits of Acceptable Change (Stankey *et al.*, 1985). Frissell's data also illustrated the curvilinear nature of the relationship between amount of use and amount of impact, although it was another 15 years before the generality of this finding and its significance to recreation management was articulated (Cole, 1981a). Frissell (1978) was also among the first to publish suggested methods for monitoring wilderness campsites.

Efforts to develop generalities and the management implications of recreation ecology were substantially increased when governmental research institutions hired recreation ecologists. Since the late 1970s (Cole, 1978), my position with the US Forest Service has allowed me to focus my professional work on recreation ecology. Jeff Marion has held a similar position with the National Park Service (now the US Geological Survey) since the mid-1980s. This has provided the opportunity for more rigorous study of recreation ecology. It has been possible to use multiple methodologies to examine impacts (Marion and Cole, 1996), to develop models of factors that influence impacts (Cole, 1987, 1992), to search for generality across different environments (Cole, 1995a), to study trends over time (Cole, 1993) and to work at multiple spatial scales (Cole, 1996). It has also provided more opportunity to apply research results to the development of management strategies (Cole, 1987, 2002; Hammitt and Cole, 1998; Leung and Marion, 2000) and monitoring techniques (Cole, 1989a; Marion and Leung, 2001).

The geographic distribution of recreation ecology research has also expanded. Prior to the 1980s, recreation ecology research was largely confined to North America and Europe. Research continues to be conducted throughout Europe, but nowhere is recreation ecology an established discipline. Occasional studies have been conducted in Japan since at least the late 1960s (Tachibana, 1969) and that traditional continues today (Yoda and Watanabe, 2000) – there and in Hong Kong (Jim, 1987;

Fig. 4.2. Much of the research in recreation ecology has been conducted in mountainous environments.

Leung and Neller, 1995). In the 1980s, research expanded in developed countries around the world, most notably in South Africa (Garland, 1987) and Australia. Notable in Australia is the work of Liddle and his students (Liddle and Thyer, 1986; Sun and Liddle, 1993a,b) and research related to management of World Heritage Areas in Tasmania (Whinam *et al.*, 1994; Whinam and Chilcott, 1999) and the Great Barrier Reef (Liddle and Kay, 1987).

In the 1990s, perhaps in response to increased ecotourism and recognition of its potential environmental consequences, recreation ecology research has expanded into developing countries and ecotourism destinations around the globe. Recent studies have been conducted in the Middle East – in Israel (Kutiel and Zhevelev, 2001) and Egypt (Hawkins and Roberts, 1993) – as well as in the tropics – in Central and South America (Boucher *et al.*, 1991; Farrell and Marion, 2001a), Africa (Obua and Harding, 1997) and South-East Asia (Jusoff, 1989). It has expanded throughout the temperate lands of the southern hemisphere – in New Zealand (Stewart and Cameron, 1992) and in Chile (Farrell and Marion, 2001b) – and even the sub-Antarctic (Scott and Kirkpatrick, 1994). Much of this generation of research has drawn directly from the research techniques and protocols developed by the original generation of recreation ecologists. Buckley and Pannell (1990) applied the findings of recreation ecology to ecotourism and Tracy Farrell applied Jeff Marion's impact monitoring procedures in Central and South America (Farrell and Marion, 2001a,b).

The ecosystems in which recreation ecology research has been conducted has expanded along with the geographical distribution of studies. The earliest work occurred in mountainous and coastal environments, due to the attraction of tourists to these locations (Fig. 4.2). To this day, the preponderance of work is still conducted in the mountains and, to a lesser degree, along coasts. Although the earliest work in the mountains was typically in the alpine and subalpine zones, recently more research has been conducted at lower elevations (e.g. Hall and Kuss, 1989; Leung and Marion, 1999a). Much of the recent coastal work has shifted to recreational impacts on reefs and intertidal areas (Liddle and Kay, 1987; Hawkins and Roberts, 1993; Rouphael and Inglis, 2002). Other environments recently studied include riparian (Marion and Cole, 1996) and desert environments (Cole, 1986).

Research Designs

Four different research designs have been employed as a means of studying recreational impacts (Cole, 1987). Each of these designs has strengths and weaknesses. The valuable perspective of each design is reflected in the fact that each was used in early recreation ecology research and each continues to be used today. The most common design, particularly in highly applied research, designed to assess impacts to an entire park, campground or trail system, is the descriptive field survey. Vegetation and soil parameters on recreation sites are measured for the purpose of assessing current conditions. Environmental and use characteristics are often simultaneously assessed and then correlated with variation in impacts to soil and vegetation. Examples of this approach include Bayfield's (1973) work on Scottish trails, as well as the work of Marion and his students on trails and campsites in the eastern USA and in Central and South America (Leung and Marion, 1999a,b; Farrell and Marion, 2001a,b). The value of this approach is that impact conditions can be surveyed over large areas rapidly and with minimal training. Surveys provide a snapshot of conditions at a point in time and, when repeated, can be used to assess trends over time. Consequently, such studies can provide much of the foundational information needed to guide day-to-day management. However, if one's goal is to understand cause-and-effect, this is the least useful of the research designs. One can speculate about cause and effect from correlational analyses, but apparent relationships can be spurious and true relationships can be missed due to the confounding of intervening variables.

A common variant of the descriptive survey is the addition of measures taken on undisturbed control sites that, when compared with recreation sites, provide an estimate of change resulting from recreation use. This amounts to using spatial differences (used versus unused) to infer temporal change (pre-versus post-use). In such studies, it is common to compare impacts on categories of sites that vary either in use or environmental characteristics. An early example is Frissell and Duncan's (1965) study of variation in impact, related to amount of use, on canoe campsites. This approach, though more time-consuming than the simple descriptive survey, has the advantage of providing an estimate of the extent to which conditions reflect recreational use. However, control sites are never perfect replicates of pre-existing conditions and, in some situations, the difficulty of finding good controls makes it impossible to use this approach.

A further variant of the descriptive field survey is the before-and-after natural experiment. This design involves assessing conditions before and after recreational use occurs, or before and after a change in management regime. Ideally, identical measures are taken on control sites that are not subjected to use or a change in management. In this case, change resulting from management is measured directly. An early example of this approach is Merriam and Smith's (1974) study of impacts resulting from initial use of newly opened campsites. Spildie *et al.* (2000) used this design to assess the effectiveness of a management programme designed to confine and reduce campsite impacts associated with packstock. Typically, such studies are conducted in one place at one point in time. Consequently, it can be difficult to assess the general applicability of results.

The three variants of the descriptive field survey have the advantage of realism and providing highly relevant site-specific information, but they all suffer, to varying degrees, in their ability to identify cause-and-effect and to contribute to general knowledge. The alternative is the simulated experimental approach. With this approach, researchers carefully control use and environmental factors in a replicated design that maximizes insights into cause and effect. Bayfield (1971) was perhaps the first to employ experimental trampling by humans, although Wagar (1961) trampled vegetation using an artificial 'tamp'. More recently, Cole and Bayfield (1993) developed a standard protocol for conducting trampling experiments. This protocol has been applied in many different vegetation types, from mountainous areas of the USA (Cole, 1995a) to such places as Arctic tundra (Monz, 2002), sand dunes in France (Lemauviel and Rozé, 2003) and forested communities in Uganda (Pratt, 1997). Widespread application of similar field techniques increases the ability to develop broad generalizations and to understand the causes of variability.

Each of these research designs has inherent strengths and weaknesses. The most appropriate approach to take will depend on the goals of the study. Maximum insight can be gained by utilizing several approaches simultaneously. For example, Marion and Cole (1996) combined: (i) descriptive field surveys of campsites, stratified according to amount of use and vegetation type, along with measures taken on adjacent controls; (ii) natural experiments on previously undisturbed sites, before and after being opened for camping; (iii) natural experiments on established campsites, before and after being closed to use, as well as before and after management actions designed to reduce campsite size; and (iv) trampling experiments.

Progress in recreation ecology is hampered by minimal attention given to conceptual and theoretical development. Early exceptions include Liddle's (1975a,b) conceptual model of trampling processes and his hypothesis that trampling tolerance is related to primary productivity. Cole's (1992) simplified model of campsites represents one of the few attempts to use analytical models to build foundational concepts regarding how various factors operate in determining impact magnitude. Rigorous analyses of the efficiency of impact assessments are also lacking, although Leung and Marion (1999c) is a notable exception.

Research Results

Descriptive information about recreational impacts can be divided into information about the nature and magnitude of impacts caused by different recreational activities, spatial aspects of impacts, and temporal patterns of impact. There is also an extensive body of information about use and environmental characteristics that influence the nature and magnitude of impacts. This knowledge provides the basis for insight into management actions that might effectively control impacts. Finally, a substantial amount of work has developed regarding the effectiveness of impact management techniques, as well as efficient ways to monitor impacts.

The nature and magnitude of impacts

Much of the research into hiking and camping impacts on soil and vegetation is focused on either linear travel routes, usually trails, or nodes of concentrated use, usually campsites but also picnic sites and viewpoints. The other tradition has been to study the effects of trampling, which occurs on trails and campsites but also away from these places of concentrated use.

Trampling has at least three effects: abrasion of vegetation, abrasion of organic soil horizons and compaction of soil (Fig. 4.3). Plants can be bruised, crushed, sheered off and even uprooted by trampling. Trampling effects include reductions in plant height, stem length and leaf area, as well as in the number of plants that flower, the number of flower heads per plant and seed production (Liddle, 1997). Reduced height and leaf area decrease the photosynthetic area of plants, resulting in depleted carbohydrate reserves (Hartley, 1999). These changes typically result in reductions in plant vigour and reproduction. Many plants are killed by trampling. At moderate levels of trampling, however, some species increase in abundance, often as a result of decreased competition or a change in microhabitat. Generally, where trampling is intense, plant cover and biomass are low, most plants are short, species richness is reduced and species composition has shifted.

Trampling compacts soils, reducing porosity, particularly the volume of macropores (Monti and Mackintosh, 1979). This reduces the water-holding capacity of soil, except in some coarse-textured soils. Compaction reduces water infiltration rates, leading to increased runoff and erosion potential. These physical soil changes alter soil chemistry and biota, although such changes are poorly understood. Compacted soils can also inhibit seed germination and plant growth. Alessa and Earnhart (2000) have shown that plants in compacted soils may be less able to utilize available nutrients because they grow fewer lateral roots and root hairs and because cytoplasmic streaming within root hairs is reduced. Soil compaction effects are exacerbated by abrasion and loss of organic soil horizons, which shield underlying mineral soil horizons from excessive compaction and erosion.

Loss of organic litter directly affects plant and animal populations, both above and below the ground. Since certain plant species germinate most frequently on organic soil surfaces,

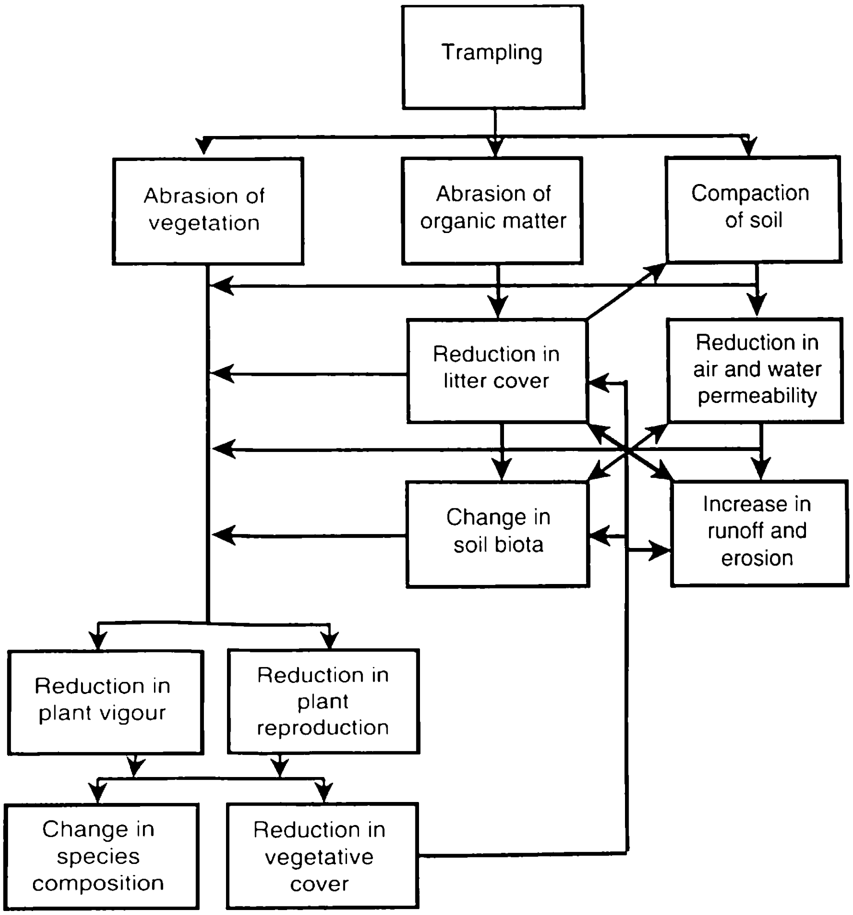

Fig. 4.3. A conceptual model of trampling impacts. Note the numerous reciprocal and cyclic relationships.

loss of litter can cause species composition to shift towards species that germinate most frequently on mineral soil. Loss of organic matter from the soil typically reduces the water-holding capacity of the soil and has an adverse effect on soil microbial populations, which depend on soil organic matter and root exudates from above-ground plants for their energy. Zabinski and Gannon (1997) report substantial reductions in the functional diversity of microbial populations on a backcountry campsite. Microbial populations contribute to ecosystem functioning by metabolizing nutrients, transforming soil organic matter, producing phytohormones and contributing to soil food webs.

The impacts of camping include all the effects of trampling, as well as some unique impacts. Numerous studies have quantified the magnitude of soil and vegetation impact on campsites. The data in Table 4.1 are typical. They describe vegetation and soil conditions on 29 paired canoe-accessible campsites and undisturbed control sites in low-elevation riparian forests in the eastern USA (Marion and Cole, 1996). On most campsites, most of the vegetation has been eliminated and the vegetation that remains consists primarily of graminoids. Forbs dominate undisturbed control sites. Organic horizons on campsites are only about one-third as thick as on controls; mineral soil is exposed over most of the campsite. These mineral soils are compacted – exhibiting increased bulk density and penetration resistance. Substantial numbers of trees have been damaged (cut branches or scarred trunks) or

Table 4.1. Vegetation and soil conditions on 29 campsites and undisturbed control sites at Delaware Water Gap National Recreation Area, 1986 (from Marion and Cole, 1996).

	Campsite		Control		
Impact parameter	Mean	Range	Mean	Range	*P*
Ground vegetation cover (%)	15	0–63	72	1–95	0.001
Floristic dissimilarity (%)	75	23–100		Not applicable	
Graminoid cover (%)	58	0–100	26	0–92	0.023
Forb cover (%)	23	0–78	59	5–100	0.001
Mineral soil cover (%)	61	21–94	1	0–15	0.001
Organic horizon thickness (cm)	0.5	0–1.4	1.5	0.2–3.1	0.002
Soil bulk density (g/cm^3)	1.26	1.0–1.4	1.06	0.7–1.4	0.001
Soil penetration resistance (kPa)[a]	275	137–382	49	0–226	0.001
Soil moisture (g/cm^3)	18	8–32	17	8–31	0.710
Felled trees (%)	19	0–53		Not applicable	
Damaged trees (%)	77	25–100		Not applicable	
Tree reproduction (stems/ha)	936	0–6275	10,090	0–56,400	0.001
Non-vegetated area (m^2)	181	0–696	0	0–15	0.001
Campsite area (m^2)	269	51–731		Not applicable	
Shoreline disturbance (m)	9	0–20		Not applicable	

[a] 1 kPa = the pressure corresponding to 1.01971×10^{-2} kg/cm^2

felled, and tree reproduction has been dramatically reduced. Along with the felling of tree saplings, lack of tree reproduction suggests that overstorey trees will not be replaced on campsites when they eventually die.

Camping also can cause off-site impacts. The most common off-site impacts are informal trailing (between the campsite and water sources, other campsites or the main trail) and impacts caused by the collection of wood to be burned in campfires. Hall and Farrell (2001) documented 25–63% reductions (depending on size class) in abundance of woody material on and around campsites. Taylor (1997) found that the density of saplings around campsites was reduced within an area that extended 45 m on average from the centre of the campsite. The most pronounced off-site impacts are often those associated with the confinement of horses and other pack animals used to transport people and gear (see Newsome *et al.*, Chapter 5, this volume).

Impacts on trails have also been studied. However, it is difficult to separate the impacts of hiking on trails from the impacts associated with trail construction and maintenance, and the impacts that would occur on trails in the absence of hiking (e.g. erosion by rainwater channelled down a trail tread). Major impacts of trail construction and maintenance include opening up tree and shrub canopies, the building of a barren, compacted trail tread that may alter drainage patterns, and the creation of a variety of new habitats, including cut slopes above the trail and fill below (Cole, 1981b). Except where hiking use is extremely high, it is probably rare for the impacts of hiking on trails to exceed the impacts caused by trail construction. However, these rare cases of profound hiking impact can be highly problematic. For example, the deep, peaty soil of tracks in much of the Tasmanian Wilderness World Heritage Area can be churned into deep quagmires by a small number of hikers (Calais and Kirkpatrick, 1986; Whinam and Chilcott, 1999).

Impacts adjacent to trails are similar to those caused by trampling. Although trampling adjacent to trails can reduce vegetation cover (Cole, 1978; Boucher *et al.*, 1991), it is common for vegetation cover to be greater adjacent to trails than on undisturbed sites (Hall and Kuss, 1989), presumably due to increased light, water and nutrients there. Organic matter can decrease and soil compaction increase (Adkison and Jackson, 1996). Vegetation composition adjacent to trails is usually very different from undisturbed site controls. It can be less diverse (Boucher *et al.*, 1991), but often is more diverse (Hall and Kuss, 1989), partially due to the invasion of exotic species that use trails as conduits for movement (Benninger-Truax *et al.*, 1992).

Of more practical significance and concern is the impact of hiking on the constructed and maintained trail surface. Constructed trails are barren and compacted by design. So, the interest here is not impacts on native soil and vegetation but impacts on the trail itself. This is a concern because hikers can increase soil erosion from trails, either by detaching or transporting soil particles. Two recent experimental studies provide insight into the process by which this occurs. They show that sediment yield and trail erosion is detachment-limited rather than transport-limited (Wilson and Seney, 1994; DeLuca *et al.*, 1998). Trail use loosens soil particles, making them easier to detach and, therefore, available to be transported by such erosive agents as running water.

Most trail-impact studies document trail characteristics, such as width and depth, without regard for the complex factors (of use, environment and management) that combine to influence these characteristics. Bayfield and Lloyd (1973) developed survey techniques for periodically assessing trail width and depth, as well as censusing the presence or absence of 'detracting' features, such as rutting and bad drainage. Coleman (1977) developed a technique for measuring trail cross-sectional area. More recent assessments of trail conditions, in such places as Guadalupe Mountains National Park (Fish *et al.*, 1981), the Selway-Bitterroot Wilderness, (Cole, 1983) and Great Smoky Mountains National Park (Leung and Marion, 1999b), are largely extensions of this early work. These studies provide descriptive statistics (means and ranges) for such metrics as trail width and depth, as well as frequency and extent of trail problems (Bayfield's 'detracting' features). For example, mean trail width and depth were 115 cm and 10 cm, respectively, on trails in the Selway-Bitterroot Wilderness (Cole, 1991). On trails in Great Smoky Mountains National Park (Leung and Marion, 1999b) there were 470 occurrences of multiple tread. A total of 10.3 km of trail (1.8% of the trail system) had multiple treads. These studies typically search for correlations between trail conditions and characteristics of use, environment and management. For example, in Great Britain, Bayfield (1973) found that trail width was positively correlated with soil wetness, roughness and steepness, and Coleman (1981) found that trail width was positively related to recreation use.

The most significant impacts of hiking on native soils and vegetation are probably those associated with proliferation of user-created trails along hiking routes where a trail tread is never constructed. Lance *et al.* (1989), describe this process in Scotland, noting that trail development usually starts with formation of a single track. As this path widens and erodes, secondary paths are created. These widen and merge with other paths, ultimately creating a braided, eroding web (Fig. 4.4). On the tallest peaks in Colorado, user-created trails to the summits have eroded so severely that they are now being replaced by constructed trails. Restoration of abandoned sections of user-created trail, which are often steep and eroding, is difficult (Ebersole *et al.*, 2002).

Spatial patterns of impact

Most studies of impact report the intensity of particular types of impact – the amount of impact per unit area (e.g. the campsite lost 50% of its vegetation cover). Assessments of magnitude of impact must also consider the area over which this impact occurs. The magnitude of a 50% cover loss on a 1000 m^2 campsite is twice that of a 50% cover loss on a 500 m^2 campsite – although the intensity of impact is the same. Magnitude of impact (sometimes referred to as aggregate impact) is minimized when both the area of impact and the intensity of impact per unit area are minimized (Cole, 1981a). Certain impact parameters only describe impact intensity (e.g. vegetation cover loss), while others only describe area of impact (e.g. campsite area). A few parameters describe both. For example, the area of vegetation loss on a campsite (Cole, 1989b) expresses vegetation loss, in m^2, as the product of campsite area and the difference between vegetation cover on the campsite and an adjacent control site. This metric makes it possible to compare the magnitude of vegetation impact on sites that vary greatly in size (e.g. Marion and Farrell, 2002).

Spatial aspects of impact have received

Fig. 4.4. Trail braiding is a common type of trail impact in certain environments.

little attention, beyond recognition that assessments of the magnitude of impact must consider the area that has been impacted, as well as the intensity of impact. In addition to the intensity and aggregate area (magnitude) of impact, other potentially important descriptors of impact include the size of impacts and the spatial distribution (pattern) of impacts. Given a constant aggregate area of impact, there may be many small impacts or a few large impacts. Theoretically, these impacts can be distributed in a pattern that is either more clumped (aggregated or underdispersed) or more regular (overdispersed) than a random pattern. In reality, spatial impact patterns are almost always more clumped than random. Campsites are clustered in campgrounds or around lakes and in places accessed by trails. Hiking impacts are concentrated along trail corridors, with little impact off trail.

Quantitative descriptions of impact vary with the spatial scale of analysis that is selected. For example, vegetation loss may be 100% at the centre of a campsite but only 50% when the entire campsite is surveyed. At the scale of a lake basin, vegetation loss associated with camping might amount to only 1 or 2% and, at the scale of the park or wilderness, less than 1% of the vegetation is likely to be lost (Cole, 1981b). Impacts might be considered few and large at a 10ha scale but many and small at the scale of 10,000ha. They may be regularly distributed at a 10ha scale but clumped at the scale of 10,000ha. What this suggests is that any quantification of impacts is only valid at the chosen scale of analysis.

Although generally ignored, spatial descriptors of impact and scaling issues are important considerations, particularly in assessing how much of a problem impacts are, and in devising strategies for managing them. Cole (1981b) noted that hiking and camping impacts on soil and vegetation, while severe when measured at small scales, are minimal at large spatial scales. This suggests that while recreation impacts can be serious for individual plants and animals, and perhaps localized rare populations, they are generally of little significance to landscape integrity or regional biotic diversity. Moreover, unless much of a population is impacted by a single impacted site, the intensity, size and distribution of impacts are not relevant to the significance of impacts assessed at large spatial scales. If animal populations are considered, however, spatial patterns in which impacts are clustered, leaving large expanses undisturbed, might be the ideal.

Recreation impacts on soil and vegetation are highly significant at the scale of human perception – the scale humans can readily observe. Studies of wilderness campers show that most campers view small areas of impact as 'posi-

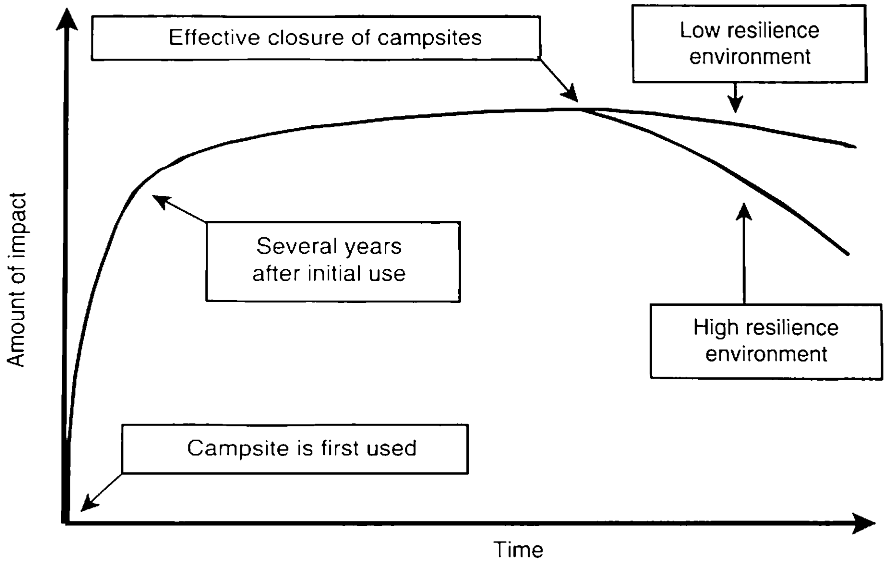

Fig. 4.5. The typical life history of a campsite, from initial use through a period of closure and recovery.

tive', 'pretty natural, healthy' (Farrell *et al.*, 2001), because they make the site function well as a temporary dwelling for humans. Perhaps from the human perspective, many small impacts are preferable to a few large impacts, because small impacts are perceived as 'healthy' dwelling sites, while large impacted areas (several hectares or more) suggest abuse, damage and unhealthy conditions. Moreover, dispersal of impacts at this scale provides more solitude and privacy for tourists. This line of thinking leads to the conclusion that, when impacts on soils, vegetation, animals and humans are all considered, they are least problematic when: (i) aggregate impact (intensity in combination with area) is minimized; and (ii) impacts are concentrated at the site scale, dispersed at intermediate scales (within a destination area such as a lake basin) and clustered at larger scales (within a park or wilderness) (Hammitt and Cole, 1998). Although little attention has been devoted to these spatial issues, Leung and Marion (1999d) suggest some spatial strategies for managing impacts.

Temporal patterns of impact

The tendency to study impacts at one point in time has contributed to a lack of data on temporal patterns of impact, much as the tendency to conduct studies at just one spatial scale leaves us with little insight into spatial patterns. Available studies suggest that individual campsites have a typical 'life history', moving successively through stages of development, dynamic equilibrium and recovery (Fig. 4.5). Impact occurs rapidly during the development phase, shortly after a campsite is first used. For example, on newly established canoe campsites, most of the impact that occurred over the 6 years following creation of the campsite occurred during the first year of use (Marion and Cole, 1996). Impact did increase over the first 3 years, but at a decelerating rate. This phase is followed by a more stable phase in which impacts change little unless there are dramatic changes in amount of use. For example, on long-established campsites in the Eagle Cap Wilderness, mean vegetation cover was 15% in 1979, 12% in 1984 and 19% in 1990 (Cole and Hall, 1992). Vegetation cover on these campsites might be expected to fluctuate between about 10% and 20%, as long as use characteristics are relatively stable. These patterns are relatively consistent across diverse ecosystem types and types of recreation, although impacts occur more rapidly (the development phase is shorter) as amount of use increases and site durability decreases. Moreover, aberrant behaviour

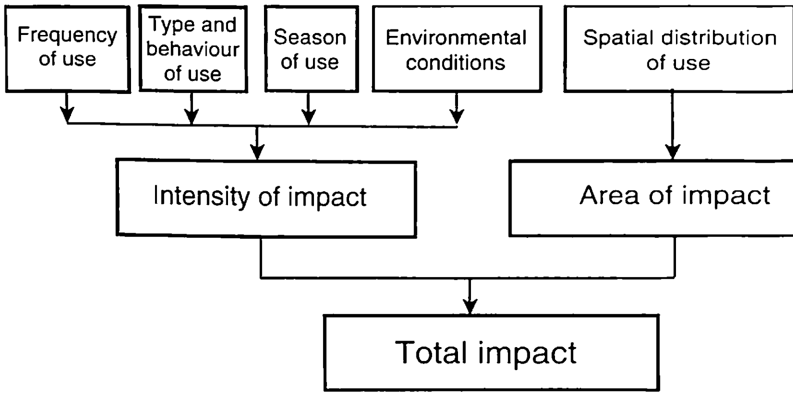

Fig. 4.6. Factors that influence the intensity and area of impact and, therefore, the total amount of impact.

(e.g. someone cutting down a tree) can cause dramatic spikes in impact at any time.

The recovery phase is almost invariably longer than the development phase, because deterioration occurs more rapidly than recovery. Recovery rates also vary greatly with kinds of impact, magnitude of impact and environment. Variation in the resilience of different ecosystem types is pronounced. Hartley (1999) reports residual effects of trampling after 30 years, in alpine meadows in Glacier National Park, while most evidence of camping on closed riparian campsites disappeared within 6 years (Marion and Cole, 1996). Cole and Monz (2002) report that an alpine grassland trampled 1000 times recovered more rapidly than a neighbouring forest, with an understorey of low shrubs, that was trampled just 75 times. Given the same environmental setting, sites that receive more use and that are more heavily impacted will take longer to recover.

Temporal patterns at larger spatial scales have generally been ignored. They are particularly important, however, because impacts tend to proliferate and spread across the landscape where use distribution is not tightly controlled. For example, in two drainages in the Eagle Cap Wilderness, the number of campsites increased from 336 in 1975 to 748 in 1990 (Cole, 1993), even though the condition of most of the sites that existed in 1975 changed little between 1975 and 1990. Site proliferation occurs because, as use shifts across the landscape, new campsites appear more rapidly than old campsites disappear.

Temporal patterns on trails and hiking routes are likely to be similar, though they have seldom been studied. Trail impacts occur rapidly; most segments on established trail systems are generally stable (Fish *et al.*, 1981; Cole, 1991); and recovery of closed trails is typically slow, except where it is assisted (Eagen *et al.*, 2000). However, trail segments that are poorly located or inadequately designed and maintained may deteriorate substantially. At large spatial scales, impacts have increased over time due to: (i) lack of recovery on re-routed trail segments; and (ii) the pioneering of routes into trailless places. This latter trend can be particularly problematic because development of a trail makes access easier, which can lead to a cycle of ever-increasing use and impact.

Factors that influence magnitude of impact

The types of research that have probably been most useful to management are studies of the factors that influence the magnitude of impacts – why impacts are minor in some situations and severe in others. The principal factors that influence intensity of impact (Fig. 4.6) are: (i) frequency of use; (ii) type and behaviour of use; (iii) season of use; and (iv) environmental conditions, while area of impact is primarily a result of the spatial distribution of recreation use (Cole, 1981a, 1987). An understanding of each of these influential variables suggests strategies for managing the impacts of hiking

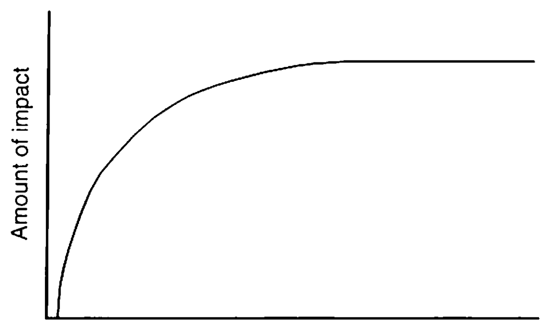

Fig. 4.7. The relationship between amount of use and amount of impact is curvilinear (asymptotic).

and camping on soils and vegetation (Cole *et al.*, 1987; Marion and Leung, Chapter 13, this volume).

The relationship between frequency of use and intensity of impact is generally asymptotic (Fig. 4.7). At first, small increases in use frequency cause pronounced increases in impact; however, the rate of increase in impact decreases as use intensity increases. Where use is light, sites that receive even small differences in amount of impact can have very different impact levels. However, where use is heavy, sites that receive substantially different amounts of use may have similar impact levels. Frissell and Duncan (1965), the first researchers to document this relationship in a field situation, concluded that 'if any use is to be allowed in the wilderness areas, some immediate loss of the natural vegetation will have to be tolerated' (p. 258). Similar results have been found in numerous field surveys of recreation sites and in experimental studies. The further implication of this relationship is that the magnitude of impacts can usually be minimized by encouraging the repetitive use of as small a number of sites as possible (i.e. concentrating use) (Cole, 1981a). This strategy involves accepting a slight increase in the intensity of impact to realize the benefits of a large decrease in the area of impact.

The type and behaviour of use can also have a profound effect on both the type and magnitude of impact. For example, campers who build fires cause both more and different types of impact than campers who do not build fires. Several studies have compared the impacts of hikers with those of groups who use horses or llamas for transport. Generally, these studies have found that horses cause more impact than hikers or llamas, which cause equivalent levels of impact (Cole and Spildie, 1998; DeLuca *et al.*, 1998). Recreation ecology research has provided the scientific foundation for minimum-impact educational programmes (Cole, 1989c). These programmes teach techniques of trip planning, route selection, hiking behaviour, campsite selection and camping behaviour that minimize the *per capita* impacts of use.

Season of use is a less critical factor for hikers than it is for horses and heavy pack animals that can cause severe damage to trails and meadows when soils are water-saturated and plants are growing rapidly. During seasons when snow banks are melting, hikers also need to avoid walking off trail and on water-saturated soils.

A substantial body of research has developed regarding characteristics that make different environments more or less durable as campsites or as trail locations. Experimental applications of both trampling (e.g. Bayfield, 1979; Cole, 1995b) and camping (Cole, 1995c) have been particularly insightful in building this knowledge. Field surveys of trails and campsites that develop correlations between impact parameters and environmental variables have also been helpful (e.g. Leung and Marion, 1999a,b). Experimental studies show that some vegetation types can tolerate more than 30 times as much use as others, with no more damage (Cole, 1995a).

Experimental studies suggest that there is an important difference between a site's resistance (its ability to tolerate use without being damaged) and its resilience (its ability to recover from damage). Cole (1995b) has shown, for groundcover plants, that resistance decreases with erectness and that broadleaved herbs are typically less resistant than grass-like plants and shrubs. Herbs growing in shade are particularly intolerant of trampling because adaptations to shading – possession of large, thin leaves and tall stems – make these plants vulnerable when trampled. This explains the common finding that trampling of forested sites generally results in more rapid loss of vegetation than trampling of open woodlands or

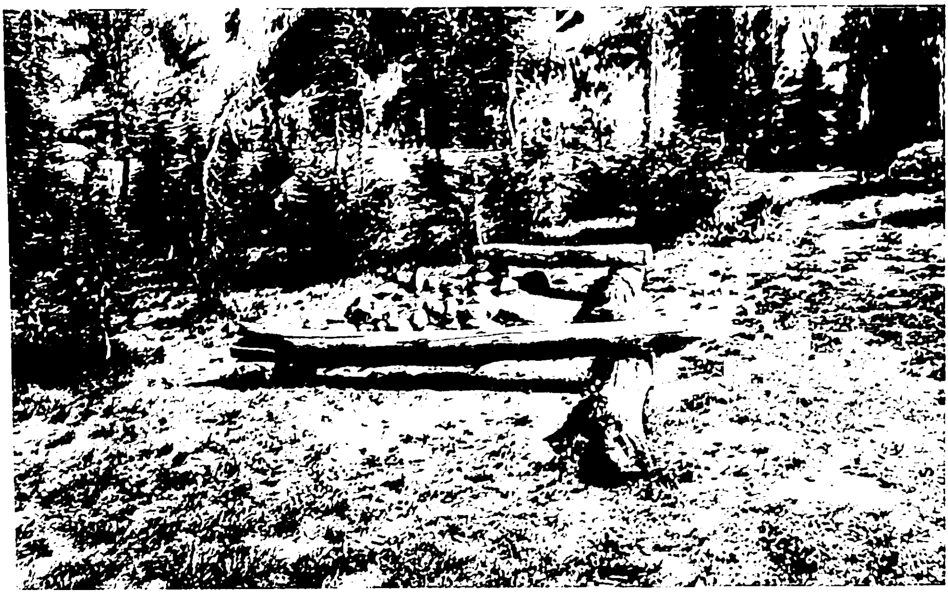

Fig. 4.8. The area of vegetation loss on this campsite is small, due to the durability of the graminoid vegetation cover.

meadows. Low shrubs, such as heather, are relatively resistant to trampling stress, but their resilience is low. Once damaged, they recover slowly. Grass-like plants are most tolerant of trampling.

At the risk of overgeneralizing about a very complex subject (refer to reviews in Cole, 1987; Liddle, 1997; Hammitt and Cole, 1998; and Leung and Marion, 2000, for further details), a few conclusions about site durability seem warranted. Characteristics of durable campsites and other nodes of concentrated use include: (i) either lack of groundcover vegetation or presence of resistant vegetation (Fig. 4.8); (ii) an open, rather than closed, tree canopy; (iii) thick organic soil horizons; or (iv) a relatively flat but well-drained site. Marion and Farrell (2002) also note the importance of designing campsites to confine impacts to a small area, in the absence of natural features such as rocky terrain that serve this purpose.

Leung and Marion (1996) provide a useful overview of knowledge regarding how environmental characteristics influence trail condition. Terrain and topography have a major influence on trail conditions. Steep trail slopes, steep side slopes and trail alignments in which the trail directly ascends slopes all tend to be more degraded, usually because more water is channelled, with more force, down the trail tread. Trail problems are also common where soils are fine-textured, stone-free and homogeneous, or highly organic and where soils are poorly drained or have high water tables. Trails also tend to widen where the ground surface is wet or rough (Bayfield, 1973).

Management and monitoring

Management and monitoring of trails and campsites are covered in detail in Leung and Marion (Chapter 14 this volume). The scientific foundation for knowledge about effective management strategies was derived from hundreds of studies of the nature and magnitude of impacts, and how they are influenced by characteristics of use and the environment. Along with the experiential knowledge developed from decades of implementing recreation management programmes, a wide array of effective management strategies has evolved (Hammitt and Cole, 1998). Similarly, decades of recreation ecology research, developing methods of measuring impact, have contributed to the campsite and trail monitoring methods employed today (Cole, 1983, 1989a; Marion, 1991; Leung and Marion, 1999b).

Conclusions and Future Directions

Although the field of recreation ecology is only about 30 years old, somewhere around 1000 studies have been conducted. A majority of these have focused on the impacts of hiking and camping on recreation and soils. Specific details about the nature, magnitude and spatial aspects of impact vary with the context of every situation (with amount and type of use, environment, management, etc.). In addition, the management objectives of every park, wilderness or other tourist destination also vary. Therefore, in every place where recreation impacts are a concern, it is worthwhile to have recreation ecology studies conducted in that area, so results can be interpreted in reference to the specific context and management objectives of the area. However, in the absence of site-specific studies and information, much insight can be gleaned from generalizations suggested by the recreation ecology literature.

Since the late 1970s, there have been several attempts to synthesize the recreation ecology literature. Each attempt, including this one, is somewhat unique but there is substantial consensus as well. The following five generalizations are among the most important and generally agreed upon.

1. Impact is inevitable with repetitive use. Numerous studies have shown that even very low levels of repetitive use cause impact. Therefore, avoiding impact is not an option unless all recreation use is curtailed. Managers must decide on acceptable levels of impact and then implement actions capable of keeping use to these levels.

2. Impact occurs rapidly, while recovery occurs more slowly. This underscores the importance of proactive management, since it is much easier to avoid impact than to restore impacted sites. It also suggests that relatively pristine places should receive substantial management attention, in contrast to the common situation of focusing most resources in heavily used and impacted places. Finally, it indicates that rest-rotation of sites (periodically closing damaged sites, to allow recovery, before re-opening them to use) is likely to be ineffective.

3. In many situations, impact increases more as a result of new places being disturbed than from the deterioration of places that have been disturbed for a long time. This also emphasizes the need to be attentive to relatively pristine places and to focus attention on the spatial distribution of use. It suggests that periodic inventories of all impacted sites is often more important than monitoring change on a sample of established sites.

4. Magnitude of impact is a function of frequency of use, the type and behaviour of use, season of use, environmental conditions, and the spatial distribution of use. Therefore, the primary management tools involve manipulation of these factors.

5. The relationship between amount of use and amount of impact is usually curvilinear (asymptotic). This has numerous management implications and is also fundamental to many minimum impact educational messages. It suggests that it is best to concentrate use and impact in popular places and to disperse use and impact in relatively pristine places.

New insights into recreation ecology have been generated as researchers have adopted multiple methodologies and expanded both the temporal and spatial scales of analyses. However, further progress is hampered by a lack of theory and conceptual thinking. Now that the field is 30 years old, the time seems ripe for conceptual and theoretical work that can build a framework for organizing the knowledge gained from the multitude of idiosyncratic field studies that have been conducted.

Two critical gaps in knowledge also limit maturation of the field. First, research needs to move beyond the easily observable and measurable effects of recreation. In particular, we need to better understand relationships between the physical, chemical and biological effects of recreation on soil, and how these soil impacts affect, and are affected by, plants. In the absence of such knowledge, attempts to restore damaged sites often fail. Plants are placed in soil that has not held plants for a half-century and the plants die (Moritsch and Muir, 1993). Soil amendments are needed before plants can survive (Cole and Spildie, 2000; Zabinski *et al.*, 2002). Restoration has been called the acid test of our ecological knowledge (Jordan *et al.*, 1987) because our ability to restore ecosystems will be dependent on the depth of our understanding and insight into how ecosystems work. By this definition, our understanding of recreation ecology is still wanting.

The lack of attention that recreation ecologists have given to the spatial aspects of recreation impacts is also problematic. Impacts have almost always been evaluated at the meso- or site-scale. Populations and communities of plants and soil pedons have been the primary unit of analysis. We have generally done a good job of describing impacts that occur at the human scale. As mentioned above, lack of research at smaller scales hampers our ability to restore damaged sites. Lack of research at larger spatial scales – regarding how landscapes and regions are impacted by recreation – limits our insight into the significance of recreation impacts. How do we answer the 'so what' questions? Hiking and camping impacts on soil and vegetation are generally severe but localized disturbances. Evaluations of these impacts at larger spatial scales would result in wiser judgements about how much of a problem these impacts are, and the most appropriate balance between impacts and access for recreation and tourism.

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