Recreation Impacts and Management in Wilderness: A State-of-Knowledge Review

Yu-Fai Leung
Jeffrey L. Marion

Abstract—This paper reviews the body of literature on recreation resource impacts and their management in the United States, with a primary focus on research within designated wildernesses during the past 15 years since the previous review (Cole 1987b). Recreation impacts have become a salient issue among wilderness scientists, managers and advocates alike. Studies of recreation impacts, referred to as *recreation ecology*, have expanded and diversified. Research has shifted its focus more towards questions driven by wilderness and park planning frameworks such the Limits of Acceptable Change and the Visitor Experience and Resource Protection. This paper begins by providing an overview of recreation impacts and their significance in wilderness, followed by a review of research approaches and methods. Major findings from recent studies are summarized. The contribution of this knowledge base to management decisionmaking and practices is examined. The paper concludes with a discussion of major knowledge gaps and suggested areas for future research.

The passage of the Wilderness Act in 1964 and the creation of the National Wilderness Preservation System (NWPS) marked a milestone in nature conservation in the United States. The system has expanded from 54 units and 9 million acres at its inception to 624 wilderness areas and 104 million acres by 1998 (Landres and Meyer 1998).

The Wilderness Act recognizes the value of wilderness recreation and specifies that unconfined and undeveloped recreational opportunities are to be provided in wilderness areas as a legitimate type of use. Results from recent recreation trends studies show that wilderness visitation has experienced impressive growth during the past three decades (Cole 1996). Hiking, overnight camping, wildlife viewing, horseback riding and nature study remain popular activities, and participation in more specialized activities, such as caving and rock climbing, is increasing. In-depth discussion of wilderness recreational use and user trends is provided in another state-of-knowledge review (Watson, this volume).

Continued growth in recreational use in wilderness has tremendous environmental, economic and social implications. This paper focuses on the environmental challenges wilderness managers face in addressing a large and expanding number of recreationists and their associated impacts. Sustaining current use and accommodating future growth in wilderness visitation while achieving an appropriate balance with resource protection presents a considerable challenge.

Scope and Definitions

Several definitions and limitations are provided here to clarify this discussion. The term *impact* is used to denote any undesirable visitor-related biophysical change of the wilderness resource. Social impacts are excluded from this review. The scope of this paper is generally limited to studies conducted in wildernesses designated by Congress. However, research studies from similar backcountry areas outside the NWPS are occasionally included for comparison. Active research in recreation impacts exists in other countries such as Australia, Britain, Canada and New Zealand, but this body of international literature deserves a separate review. Finally, this paper limits its scope to recreation impacts generated from within wilderness boundaries, although recreational use and development outside wilderness boundaries can pose an external threat to the integrity of wilderness resources (Cole and Landres 1996).

The Field of Recreation Ecology

Negative impacts on wilderness are an inevitable consequence of recreation. Even the most thoughtful visitors would leave footprints and unintentionally disturb wildlife. As recreation is a legitimate use in wilderness areas, the issue for managers is at what level do resource impacts become unacceptable based on wilderness management goals and mandates.

Recreation activities can cause impact to all resource elements in a wilderness ecosystem. Soil, vegetation, wildlife and water are four primary components that are affected (Table 1). Because various ecological components are interrelated, recreation impact on a single ecological element can eventually result in effects on multiple components (Hammitt and Cole 1998). The scientific study of recreation impacts, also referred to as *recreation ecology*, is a research response to the knowledge gaps and information needs about ever-growing visitor impacts in wilderness as well as other protected areas.

Recreation ecology can be defined as the field of study that examines, assesses and monitors visitor impacts, typically to protected natural areas, and their relationships to influential factors (Hammitt and Cole 1998; Liddle 1997; Marion 1998). Such knowledge can help managers identify and evaluate resource impacts, facilitating understanding of causes and

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Yu-Fai Leung is Assistant Professor, Department of Parks, Recreation and Tourism Management, North Carolina State University, Raleigh, NC 27695-8004 U.S.A., e-mail: yu-fai_leung@ncsu.edu. Jeffrey Marion is Unit Leader and Scientist, USGS Patuxent Wildlife Research Center, Virginia Tech Cooperative Park Studies Unit, Blacksburg, VA 24061-0324 U.S.A., e-mail: cpsu@vt.edu

Table 1—Common forms of recreation impacts in wilderness.

	Ecological component			
	Soil	**Vegetation**	**Wildlife**	**Water**
Direct effects	Soil compaction Loss of organic litter Loss of mineral soil	Reduced height and vigor Loss of ground vegetation cover Loss of fragile species Loss of trees and shrubs Tree trunk damage Introduction of exotic species	Habitat alteration Loss of habitats Introduction of exotic species Wildlife harassment Modification of wildlife behavior Displacement from food, water and shelter	Introduction of exotic species Increased turbidity Increased nutrient inputs Increased levels of pathogenic bacteria Altered water quality
Indirect/ derivative effects	Reduced soil moisture Reduced soil pore space Accelerated soil erosion Altered soil microbial activities	Composition change Altered microclimate Accelerated soil erosion	Reduced health and fitness Reduced reproduction rates Increased mortality Composition change	Reduced health of aquatic ecosystems Composition change Excessive algal growth

effects and improving insights regarding the prevention, mitigation and management of problems. In a broader sense, recreation ecology may be conceived as the study of ecological interrelationships between humans and the environment in recreation/tourism contexts (Leung and Marion 1996; Wagar 1964). Under this broader definition, recreation ecologists are also interested in how environmental attributes influence the availability and quality of recreation opportunities.

Recreation ecology began in the 1920s and '30s (Bates 1935; Meinecke 1928), although earlier observations of visitor impacts are available (Liddle 1997). However, substantial scientific work in this field did not occur until the late 1960s, when backcountry and wilderness visitor use in the United States increased sharply, along with associated resource impacts. A modest body of literature accumulated during the ensuing two decades and several conferences devoted specifically to recreation impacts were held (Bayfield and Barrow 1985; Ittner and others 1979; IUCN 1967). Since the mid-1980s, the study of recreation ecology has been expanding, diversifying and shifting its focus (Table 2).

Results of recreation ecology research in wilderness are disseminated in various forms, including scientific journals, conference proceedings and management reports. Some of the common journal outlets include *Biological Conservation*, *Environmental Conservation*, *Environmental Management*, *International Journal of Wilderness*, *Journal of Applied Ecology*, *Journal of Environmental Management* and *Journal of Soil and Water Conservation*. As findings and knowledge accumulated from these studies, monographs that synthesized the research literature and management applications of recreation ecology began to appear (Edington and Edington 1986; Hammitt and Cole 1998; Knight and Gutzwiller 1995; Kuss and others 1990; Liddle 1997). Knowledge generated from research has also been applied to the management of wilderness resources and visitors, although many of these applications have not been documented in the published literature.

Cole (1987b) provided a succinct account of the historical development of recreation ecology, noting that there was only a small group of scientists who consistently conducted studies in this field. Fifteen years have passed since this

Table 2—The development and major events of recreation ecology research.[a]

Approximate time period	Development/event(s)
1990s	Refinement of methods; new topics and perspectives
1980s	Integration with management frameworks
1970s	Period of active research
1960s	Period of rapidly increasing use and impact
1940-50s	First scientific studies in the United States
1930s	First experimental trampling studies in the United Kingdom
1920s	Early observations and descriptions of the problem

[a]Partly based on Cole (1987b).

review, and Cole's statement remains valid. The size of the research community in this field is still not commensurate with the extent of the problems. Currently, the study of recreation impacts and their management attracts a growing yet still small number of scientists or students, even though wilderness and other resource managers increasingly require visitor impact assessment and management assistance.

Recreation Ecology Research in Wilderness

Generally, recreation ecology studies in wilderness have enjoyed better support from the USDA Forest Service, primarily at the interagency Aldo Leopold Wilderness Research Institute (formerly Wilderness Research Unit of the Intermountain Research Station). As a result, the majority of recreation ecology studies have been conducted in wilderness areas managed by the Forest Service. Less research has been conducted in USDI National Park Service-managed wilderness areas, with some notable exceptions, such as Shenandoah and Yosemite National Parks. Very little research has been conducted in wildernesses managed by USDI Bureau of Land Management and USDI Fish and Wildlife Service.

David Cole, Forest Service, has produced a substantial number of publications and has been influential in the building of a recreation ecology knowledge base. Jeffrey Marion, Virginia Tech Cooperative Park Studies Unit (USGS Patuxent Wildlife Research Center), has conducted numerous recreation ecology studies in national parks, with a primary focus on refining impact assessment, monitoring and management techniques. A smaller institutional research effort is supported by the National Outdoor Leadership School (NOLS), led by Christopher Monz. Recreation ecology studies are also conducted by faculty members and graduate students at several academic institutions such as Clemson University, Colorado State University, North Carolina State University, University of Idaho, University of Montana and Virginia Tech.

The Significance of Recreation Impacts

Why should we care about recreation impacts? Recreation impacts are significant because they reflect success in meeting two primary legal mandates: resource protection and recreation provision. Derived from the Wilderness Act, these mandates state that wilderness areas "shall be administered for the use and enjoyment of the American people in such manner as will leave them unimpaired for future use and enjoyment as wilderness, and so as to provide for the protection of these areas [and] the preservation of their wilderness character..." (Public Law 88-577, 1964). The Wilderness Act thus identifies two concerns relative to recreation impacts: (1) protection of the integrity of wilderness environments, and (2) protection of the quality of recreational experiences. A minimal system of trails and campsites is generally viewed as essential to support recreational use of wilderness. Wilderness managers must therefore be willing to accept some degree of resource degradation associated with the creation, maintenance, and use of these recreation facilities. However, excessive resource degradation of facilities and the proliferation of user-created trails or unnecessary campsites are viewed as unacceptable.

The managerial significance of recreation impacts is also reflected in the substantial costs incurred by managing agencies to construct, maintain and rehabilitate trails and campsites, and to operate visitor management programs. While some of these costs reflect provisions for recreational use, many are directed at avoiding or minimizing recreation impacts. For example, a trail both facilitates wilderness travel and concentrates recreation traffic and impact along a single narrow tread designed and maintained to minimize resource impacts.

Resource Protection

How and to what extent recreation impacts affect the integrity of wilderness environments and natural processes have not been thoroughly examined. We do know that many wilderness areas have extensive networks of trails and campsites which are frequently in poor condition (Marion and others 1993; Washburne and Cole 1983). Cole (1990a) suggests that impacts which seriously disrupt ecosystem function and that either occur over very large areas or affect rare ecosystems are most significant. In particular, long-term or irreversible changes are problematic.

Several studies show that recreation impacts relatively small proportions of wilderness areas. For example, campsite monitoring at the heavily visited Great Smoky Mountains National Park (83% of which is recommended for and managed as wilderness) located and assessed 327 backcountry campsites and shelters with an aggregate disturbed area of 550,824 ft^2 (Marion and Leung 1997). The Park's 930 miles of trails contribute an additional 9,820,800 ft^2 of recreation-related disturbance, assuming a conservative average trail width of two feet. While these values may seem large, they represent only .05 percent of the Park's total acreage. Campsite monitoring surveys of six less visited wilderness areas in Virginia's Jefferson National Forest revealed camping had disturbed only .0007 to .015 percent of the wilderness (Leung and Marion 1995). Vegetation disturbance resulting from use of areas adjacent to campsites and trails would likely only double or triple these areal estimates.

While recreation impacts directly affect small percentages of wilderness areas, the effects are usually distributed unevenly due in part to visitor use patterns (Lucas 1990b), with intensive disturbance in some places and less intensive disturbance in surrounding areas. However, even localized impact can harm rare or endangered species, damage sensitive resources or diminish ecosystem health. For example, the collection and burning of firewood in desert ecosystems and at high elevations, where wood production is low, can disrupt nutrient cycling critical to plants that depend upon organic matter and nutrients contained in woody debris (Fenn and others 1976). Furthermore, certain forms of impact (such as soil loss) and certain environments (such as alpine meadows) have extremely low resource recovery rates, requiring long periods to recover from even limited degradation (Liddle 1997).

Visitor impacts may also extend far beyond localized use areas (Cole 1990a). Hunting and fishing directly alter the abundance, distribution and demographics of wildlife and can lead to changes in the relative abundance and composition of nongame fauna and flora (Knight and Cole 1991). The introduction and stocking of fish, particularly introduced species, alter aquatic food webs and have been cited as a contributing cause to the decline of native species (Liddle 1997). Similarly, the introduction of exotic plant species in wilderness is widespread, and some naturalized species are able to alter plant dynamics over large areas (Marion and others 1986). Other examples include stream sedimentation from trail and campsite erosion, which reduces the quality of aquatic habitats for insect and fish populations.

The mere presence of visitors may harm wildlife by displacing them from essential habitats or disrupting their raising of young (Knight and Cole 1995; Liddle 1997). Trail networks and campsites may cause a landscape fragmentation effect similar to that of roads, possibly interfering with movement of some animal species (Noss and Cooperrider 1994).

Impacts to Visitors

Recent studies suggest that perceived impacts can degrade the quality of visitor experiences (Roggenbuck and others 1993; Vaske and others 1982). Perceptions are based on how visitors believe impacts affect the overall attributes of the setting like scenic appeal or solitude, and whether or not the impacts are considered to be undesirable (Lucas 1979; Whittaker and Shelby 1988). Visitors appear to be more sensitive to impacts caused by inappropriate behavior, such as litter and tree damage, and to particularly obtrusive examples of physical impacts, such as badly exposed tree roots.

Surveys of wilderness visitors reveal considerable variability in visitor responses to recreation impacts. While several earlier studies found that visitor satisfaction was not diminished by trail and campsite impacts (Knudson and Curry 1981; Lucas 1979), Roggenbuck and others (1993) reported that littering and human damage to campsite trees were among the most highly rated indicators affecting the quality of wilderness experiences. Similarly, wilderness visitors rated ground vegetation loss and bare ground on campsites as two important determinants of their satisfaction (Hollenhorst and Gardner 1994).

The mere presence of trails and campsites, particularly those in degraded condition, also remind visitors of those that preceded them. The proliferation and high densities of trails and campsites in popular locations give wilderness a “soiled” or “used” appearance, in contrast to the ideal of a pristine wilderness. Particularly in remote areas, the discovery of even a single trail or campsite can diminish opportunities for solitude.

Impacts associated with a specific type of use may intensify perceived crowding and conflict between different visitors or groups (Vaske and others 1982). For example, horse manure or excessive muddiness on trails or trash at hunting camps might provoke negative impressions about horseback riders among other wilderness users. Such negative reactions could polarize user groups and lead to tensions with land managers.

Finally, recreation impacts such as trail rutting and excessive muddiness can provoke visitor dissatisfaction by increasing the difficulty of hiking and making it an unpleasant experience. Such impacts may also jeopardize visitor or packstock safety and increase agency liability.

Research Methods

Since the previous review (Cole 1987b), there has been a steady increase in the diversity and sophistication of research methods employed to investigate recreation resource impacts in wilderness. Research methods range from simple qualitative descriptions of impact conditions to controlled laboratory experiments with elaborate experimental designs. Some studies involved intensive and sophisticated measurements but included only a limited number of sample sites. Other studies encompassed a large number of sample sites distributed over a large landscape but often involved rapid field observations and measurements. Studies of various approaches and designs generally complement each other in developing a thorough understanding of recreation impacts. These studies, if well designed and executed, can yield useful data for wilderness managers. The choice of methods is essentially based on the research questions asked, types of data needed, character of study area, the training of investigators and logistical constraints.

Major Research Questions and Themes

1. What types of recreation impact exist?

Previous studies have documented the obvious and direct forms of recreation impact, including the area of disturbance, tree damage, soil exposure, soil erosion, vegetation loss, trash, human waste and wildlife disturbance. Among these, soil and vegetation attributes are most frequently measured (Hammitt and Cole 1998). Less attention has been paid to less visible environmental qualities, such as bacteriological water quality, soil microbial communities and wildlife physiology. However, the number of studies on these ecological components has been increasing in recent years (Knight and Gutzwiller 1995; Zabinski and Gannon 1997).

Indirect or secondary effects of recreational use, such as increased predation rates on wildlife displaced by recreation visitation, have seldom been examined. In addition, the types of recreation impacts examined have been restricted in spatial, temporal and ecological scales (Cole and Landres 1996). Few studies have investigated ecosystem or landscape-level effects. As the popularity of non-conventional types of recreational activity and equipment increases, new forms of recreation impact are likely, which will require further research, assessment and monitoring. Caving, rock climbing, llamas as pack animals, and use of hiking poles are some more common examples.

2. What is the magnitude and significance of recreation impacts?

Knowledge of the magnitude of impacts is needed to evaluate their ecological and social significance and acceptability, and to prioritize management and maintenance needs. The magnitude of recreation impacts is often judged by two components: the intensity of impact and the spatial qualities of impact (Clark and Stankey 1979; Cole 1994). The assessment of impact intensity has received more attention than the spatial component (Cole 1989c). Examples of spatial qualities include spatial extent, distribution and association of impacts. Spatial extent is perhaps the most examined spatial quality, although recent studies have begun to investigate the distribution of impacts in space (Cole 1993a; Leung and Marion 1998; McEwen and others 1996).

As mentioned earlier, a number of studies have examined the social significance of recreation impacts (Knudson and Curry 1981; Marion and Lime 1986; Roggenbuck and others 1993; Shelby and Shindler 1992; Shelby and others 1988). Two important issues—perception and acceptability of impacts to visitors and managers—are beyond the scope of this paper.

3. What is the relationship between amount of use and intensity of impact?

Research addressing this question was highlighted by the concept of carrying capacity and its application to recreation and park management. One objective of this large body of research has been to determine a threshold level of use beyond which recreation impacts will intensify. Unfortunately, these studies often concluded that the use-impact relationship is both complex and situational, depending on a diverse array of environmental and social factors. Recognizing limitations of the traditional carrying capacity model, recent work has been redirected at determining appropriate indicators and standards that reflect explicit levels of acceptable impacts. A detailed discussion on recreation carrying capacity is provided in another state-of-knowledge review (Manning and Lime, this volume).

4. What factors contribute to the problem?

Although amount of use is the most studied factor influencing recreation impacts, other use-related and environmental factors interact to determine the intensity and extent of impacts (Hammitt and Cole 1998; Leung and Marion 1996). Visitor and site management actions can moderate many of these factors and thus influence the quality of impacts (Marion 1995).

5. Have conditions worsened or improved over time?

Recent studies have examined trends of recreation impacts over time. The increasing availability of long-term monitoring data sets permits such analyses. Examples include trail monitoring (Cole 1991), campsite monitoring (Cole 1993a; Cole and Hall 1992) and a 30-year trampling/trail study in Glacier National Park (Hartley 1999).

6. How effective are visitor and site management actions?

As wilderness managers implement various visitor and site management actions to reduce or contain resource impacts, they need to know which actions have the greatest chance of success (Hammitt and Cole 1998). An example is the national Leave No Trace (LNT) outdoor skills and ethics program. Little research has been conducted to evaluate the effectiveness of recommended LNT practices in reducing the intensity and extent of impact.

7. How can research and impact assessment methods be improved?

Methodological improvements address the accuracy and precision of different methods, as well as the need to make procedures more efficient. The possibility of reducing the number of indicators for campsite assessment and monitoring has been addressed (Gettinger and others 1998; Leung and Marion 1999b), as has the choice of sampling interval for trail assessment and monitoring (Leung and Marion 1999c).

Research Approaches and Designs

A substantial number of recreation ecology studies during the past three decades were associated with the carrying capacity framework (Sumner 1942; Wagar 1964). Research approaches and methods were developed for evaluating the relationship between amount of use and intensity of impact. Another group of studies has evaluated relationships between environmental attributes and the quality of recreation impacts. For instance, a significant portion of trail research was devoted to environmental influence on trail degradation, including soil compaction, trail widening and soil erosion (Leung and Marion 1996). Experimental studies on trampling effects have also been conducted to evaluate the relative resistance and resilience of various vegetation types (Cole 1988; Cole 1993b; Cole 1995b; Cole 1995c; Marion and Cole 1996). Most recently, with the increasing adoption and implementation of the *Limits of Acceptable Change* (LAC) framework (Stankey and others 1985), the *Visitor Impact Management* framework (Graefe and others 1990) and the *Visitor Experience and Resource Protection* (VERP) framework (National Park Service 1997a; National Park Service 1997b), recreation ecology studies have begun to focus on the selection of indicators, standards and monitoring protocols to support these management planning processes (Belnap 1998).

Cole (1987b) discussed the following four major study designs in recreation ecology studies (Table 3). The ability of these designs to isolate cause and effect varies.

1. Descriptive surveys of recreation sites.
2. Comparisons of used and unused sites.
3. Before-and-after natural experiments.
4. Before-and-after simulated experiments.

Trampling and wildlife impact studies tend to adopt before-and-after experimental designs with controls, while trail and campsite condition assessments often adopt the first two designs with few exceptions (Cole 1995a). A large number of recent studies were still conducted within a short time-frame, although more long-term assessment and monitoring studies on recreation impacts have emerged.

In addition to these four types of research design, a few conceptual and simulation studies have been published (Cole 1992; Leung and Marion 1999c). Such studies are likely to increase with continued advancements and expanding application of geographic information systems (GIS) and statistical software programs.

Research Methods and Techniques

Research methods for four specific topics are discussed in this subsection. These topics, which include trampling studies, trail impacts, campsite impacts, and indicators and indices, are highlighted because they constitute a large portion of the recreation ecology literature.

Trampling Research—Trampling studies are often regarded as basic research in recreation ecology (Liddle 1997).

Table 3—Four common study designs employed in recreation ecology research with recent examples.[a]

Study design	Description	Recent example(s)
Descriptive surveys	Estimates or measurements are taken on recreation sites to assess current resource conditions	*Trails and Campsites*: Cole and others (1997); Rochefort and others (this volume)
Comparison of used and unused sites	Measurements are taken on recreation sites and nearby undisturbed sites (control) and compared to infer amount of impact	*Trails*: Hall and Kuss (1989) *Campsites*: Marion and Leung (1997); Monz (1998); Zabinski and Gannon (1997)
Before-and-after natural experiments	Measurements are taken before and after (1) commencing or ceasing use of sites, or (2) applying management action(s) to sites to infer amount of impact due to the change	*Trails*: Doucette and Kimball (1990) *Campsites*: Marion (1995); Spildie and others (this volume)
Before-and-after simulated experiments	Measurements are taken before and after treatments (including known type, frequency and intensity of use) are applied, often with random assignment, to infer amount of impact due to the treatment	*Trampling*: Cole (1993b, 1995d); Cole and Spildie (1998); Hartley (1999) *Trails*: DeLuca and others (1998) *Campsites*: Cole (1995a)

[a]Partly based on Cole (1987b).

As such, experimental designs usually employ varying trampling intensities, randomly assigned to replicated experiment plots or lanes. Known intensities or frequencies of trampling are applied by artificial or human tramplers.

Most trampling studies have been directed at the relationship between amount of use and intensity of impact and the different susceptibilities of plant species or vegetation types. A few studies have assessed the effects of different types of tramplers, such as human and horses. Recent trampling studies have included new use-related variables such as shoe type and trampling weights (Cole 1995d) and emerging types of use such as llamas (Cole and Spildie 1998).

The designs of these trampling studies varied significantly across different studies, limiting valid comparisons (Bayfield and Aitken 1992; Kuss 1986a). In response to the need for standardized procedures, trampling experiment protocols and guidelines have been proposed (Cole and Bayfield 1993).

Methods for Studying Trail Impacts—Early research on trail impacts focused on impact severity and environmental factors affecting trail degradation (Leung and Marion 1996). Very few data sets exist on temporal change of trail conditions, with an exception of a 11-year trail assessment conducted in the Selway-Bitterroot Wilderness of Montana (Cole 1991). A variety of trail assessment and monitoring techniques have been developed (Cole 1983), which can be classified into three approaches (Table 4). These techniques, many of which have been applied to wilderness, include condition class assessments (Cole and others 1997), evaluation of aerial photos (Coleman 1977; Price 1983) and quantitative measurements and experiments (Bratton and others 1979; DeLuca and others 1998; Hall and Kuss 1989). Improving some of these methods has been the subject of several recent studies. In the Eastern U.S., a problem-assessment method was developed and applied to Great Smoky Mountains National Park (Leung and Marion 1999a; Marion 1994a). The sampling issue of trail assessment methods has also been examined (Leung and Marion 1999c).

In Montana, the influence of use type on trail erosion was examined using trampling and rainfall simulation experiments (DeLuca and others 1998). Intrusion experiments were also conducted in several studies by Gutzwiller and his colleagues to examine disturbance of birds by walkers on existing trails or trailless experiment sites (Gutzwiller and Anderson 1999; Gutzwiller and others 1998; Gutzwiller and others 1994; Riffell and others 1996).

Methods for Studying Camping Impacts—Due to activity concentration and duration of stay, campsites receive the highest level of visitor impacts, particularly those related to inappropriate behavior. Campsite impact assessment approaches range from condition class (Frissell 1978) and photographic approaches (Magill 1989) to more intensive quantitative measurements (Table 5). These procedures provide managers with objective data on campsite conditions, both at a general level (reconnaissance approach) and for individual resource indicators (multiple-indicator approach). Replicating procedures allow monitoring of changes in campsite conditions, which can be used to document trends in site conditions and to evaluate the effectiveness of management actions.

Interrelationships between campsite impacts and use-related or environmental factors often require the application of more complex research designs. An interrelated set of recreation ecology studies within backcountry zones of three Eastern national parks provides an example (Cole and Marion 1988; Marion and Cole 1989; Marion and Cole 1996).

Table 4—A summary of different trail impact assessment and monitoring approaches and designs.

	Reconnaissance approach		Sampling-based approach		Census-based approach	
Item	**Condition class**	**Photo appraisal**	**Point sampling**	**Point-quadrat sampling**	**Sectional evaluation**	**Problem assessment**
Implementation	Descriptive classes are defined and assigned to trails/segments	Trails are identified and evaluated from aerial photos	Measurements are performed at a series of points along a trail that is determined by a sampling scheme	Measurements are performed within quadrats at a series of points that is determined by a sampling scheme	Trail is divided into sections; evaluation is made for each section	Impact problems are defined, followed by complete census of these problems
Unit of observation	Segment/trail	Trail/regional	Site (point)	Site (quadrat)	Segment	Dimension of impact problem
Typical data type(s)	Nominal/ordinal	Interval/ratio	Interval/ratio	Interval/ratio	Ordinal/ percentage	Interval/ratio
Major utility	Prompt assessment of trail conditions	Detect proliferation of trail networks; detect new trails	Quantitative data for statistical analysis; adaptable to management frameworks	Quantitative data for statistical analysis; adaptable to management frameworks	Prompt assessment of trail conditions and their spatial variations	Data on the frequency, extent, and distribution of impacts; adaptable to management frameworks
Limiting factor(s)	Singular qualitative measure; conflicting criteria within a condition class	Availability; resolution of aerial photos; photo interpretation skills	Relocation of sampling points; measurement error; field time	Relocation of sampling points; measurement error; field time	Definition of section; scale dependence of results	Quantitative definition of impact problems; interrater variability
Examples	Cole and others (1997)	Coleman (1977); Price (1983)	Cole (1991)	Hall and Kuss (1989)	Bratton and others (1979)	Marion (1994a); Leung and Marion (1999a)

Multiple-indicator measurements taken on campsites and paired control sites over five years were recorded and analyzed to evaluate the effect of: (1) different amounts and types of use, (2) different environmental settings, (3) temporal variation in vegetation and soil conditions, (4) initial degradation following campsite creation, and (5) initial recovery following campsite closure.

In the past 15 years, refinement of campsite impact assessment procedures for monitoring has received more emphasis. This work has been driven by management needs for longitudinal data to support management planning frameworks and decisionmaking. Refinement has occurred through numerous applications of these procedures in the Western (Cole 1993a; Gettinger and others 1998), Central (McEwen and others 1996; Williams and Marion 1997; Farrell and Marion 1997) and Eastern U.S. (Cole and Marion 1988; Leung and Marion 1995; Marion 1991; Marion 1994b; Marion and Leung 1997; Marion and Snow 1990; Williams and Marion 1995). Attempts have been made to standardize campsite assessment procedures (Marion 1991). There have also been refinements of assessment and analytical procedures and adaptation of assessment procedures to different environment types (Gettinger and others 1998; Leung and Marion 1999b; Monz 1998).

Impact Indicators and Indices—To a large extent the increased emphasis on indicators and indices over the past 15 years was a direct result of the adoption and implementation of standards-based management frameworks such as LAC and VERP. Judicious selection and periodic monitoring of indicators are critical components in these management frameworks.

An indicator may be broadly defined as an important quality that indicates resource change due to recreational use. Watson and Cole (1992) and Merigliano (1990) provided reviews and examples of indicators adopted or proposed in the wilderness management literature. Examples include amount of bare ground on a campsite, number of cut trees, incision depth of a trail and flush distance of an avian species.

In contrast, an index is generally referred to as a mathematical combination of two or more indicators (Westman 1985). They are constructed to simplify and facilitate the communication and evaluation of results. These impact indices may be classified into four groups. First, indices of impact intensity are constructed to represent the severity of environmental damage. Two examples are floristic dissimilarity and cover alteration (Cole 1978; Cole 1993b). Shannon-Wiener species diversity index (H) and community similarity index,

Table 5—A summary of different campsite impact assessment and monitoring approaches and designs.

Item	Reconnaissance approach: Condition class	Reconnaissance approach: Photo appraisal	Multiple-indicator approach: Ratings	Multiple-indicator approach: Quantitative measurement
Implementation	Descriptive classes are defined and assigned to each campsite	Site photo is taken and evaluated for each campsite	Assessment at ordinal scale is made on each selected indicator on a campsite	Measurement is taken for each selected indicator on a campsite
Typical data type(s)	Nominal/ordinal	Interval/ratio	Ordinal	Interval/ratio
Major utility	Prompt characterization of campsite conditions	Visualize campsite conditions; relocation	Efficient field work; minimal training required	Accurate and precise; permit quantitative analysis; allow aggregate measures; adaptable to management frameworks
Limiting factor(s)	Singular measure; conflicting criteria within a condition class	Scale and quality of aerial photos; photo interpretation skills	Composite ratings may not be mathematically appropriate	Field time; staff training; accuracy and precision
Examples	Frissell (1978); Marion (1995)	Magill (1989)	McEwen and others (1996)	Marion (1991); Marion and Cole (1996)

two indices commonly used in the ecological literature have also been employed (Hall 1989). Indices of spatial qualities may also be constructed to represent the spatial extent and distribution of impacts. Examples include the index of trail area (Cole and others 1997), the campsite expansion index (Gettinger and others 1998), Gini coefficients and linear nearest neighbor index (Leung and Marion 1998). The third group of indices provides a summary of resource condition of a site (Marion 1991). Area of vegetation loss (Cole 1989a), summary impact index (Cole and Hall 1992; McEwen and others 1996) and the impact index (Stohlgren and Parsons 1992) are some examples of summary indices. The final group of indices are designed to represent environmental sensitivity to impacts. Examples include the resistance and resilience indices (Cole 1995b; Cole 1995c) and the durability index (Cole 1993b).

Research Results

Since the last review more than a decade ago (Cole 1987b), there has been substantial progress in knowledge and understanding of recreation impacts and in practices of impact management. Study locations have expanded, and research topics and methods have been diversified. Many studies have focused on vegetation and soil parameters, and most have investigated impacts on campsites and trails. However, there has been more work on wildlife impacts, impact assessment and monitoring techniques and the effectiveness of management actions.

Much of this section is organized by two primary locations where recreation impacts occur—trails and campsites, with emphasis placed on studies conducted between 1986 and 1999. Earlier studies are reviewed by Cole (1987b). More extensive reviews are presented in Hammitt and Cole (1998), Kuss and others (1990) and Liddle (1997). A comprehensive bibliographic database of the recreation ecology literature is being developed as an update of the previous compilation (Cole and Schreiner 1981). This searchable database will be accessible online through the Aldo Leopold Wilderness Research Institute web site (http://www.wilderness.net/Leopold/default.htm).

Trail-Related Impacts

Soil and Vegetation Impacts—Trail construction and use can have substantial impacts to soil and vegetation, including soil compaction, erosion, muddiness, loss of vegetative groundcover and changes in species composition. Most recent research on soil and vegetation related trail impacts has been conducted outside wilderness and in other countries (Figure 1). This body of literature is beyond the scope of this paper but has been reviewed by Hammitt and Cole (1998), Kuss and others (1990) and Liddle (1997). A few studies were conducted in wilderness or similar backcountry areas. For example, Hall and Kuss (1989) investigated vegetation change along backcountry trails in Shenandoah National Park, Virginia. They found that groundcover and species diversity increased closer to trails, a finding they

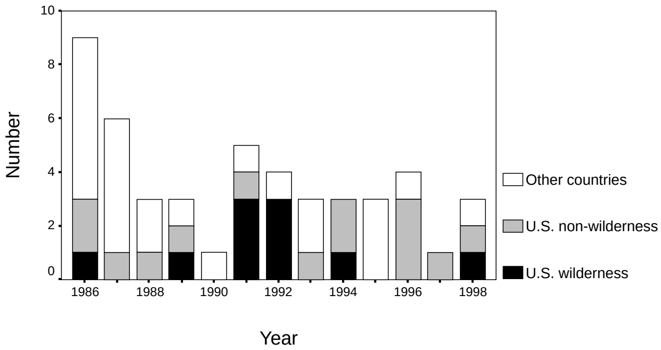

Figure 1—The numbers of publications on trail impacts between 1986 and 1998 (based on the literature that was available to the authors when this paper was prepared).

attributed to environmental alterations along trail corridors (Hall and Kuss 1989).

Trail impacts are influenced by a diverse array of use-related and environmental factors. Many studies identified environmental factors to be more important in determining the levels and rates of trail incision and associated soil erosion than use-related factors (Leung and Marion 1996). Environmental information may not be useful to predict trail impact problems in some cases, however (Burde and Renfro 1986). For example, trail widening is often associated with amount of use than site attributes (Cole 1991).

Trail impact assessments in Great Smoky Mountains National Park found that heavily used trails had significantly more soil erosion and tree root exposure, while trails receiving a high proportion of horse use were significantly wider, muddier and had more multiple treads (Leung and Marion 1999a; Marion 1994a). Trails located on ridgetops and upper slopes exhibited the greatest erosion, probably due to higher precipitation rates, more open forest canopies and reduced root mass from woody vegetation. Ridgeline trails also often directly ascend slopes, hindering the removal of water from treads of embedded trails. Problems with tread muddiness were most common in valley bottom positions, where treads commonly become embedded in moist organic soils. The number of tread drainage features (for example, water bars or drainage dips) was not correlated with these impacts, suggesting that increased trail maintenance is not a substitute for good trail positioning and layout. A recommended solution to both problems was trail relocation to valley walls with side-hill construction methods.

Introduction of Exotic Species—Cole (1987b) noted the paucity of research on recreation as a means of introducing exotic plant species into wilderness. Several studies have recently investigated this issue in greater detail. In Glacier National Park, Tyser and Worley (1992) found that trail corridors were an effective conduit for introducing exotic species such as Canadian bluegrass (*Poa compressa*), Kentucky bluegrass (*Poa pratensis*) and common selfheal (*Prunella vulgaris*) to fescue (*Festuca*) grasslands. Exotic species richness remained at high levels 330 ft from the sampled backcountry trails (Tyser and Worley 1992). In Rocky Mountain National Park, exotic species richness was found to be negatively correlated with distance from the trailhead (Benninger-Truax and others 1992). In contrast, Marcus and others (1998) reported a less serious problem with exotic species in the Selway-Bitterroot Wilderness, Montana. They found that spotted knapweed was present only along limited portions of 5 sampled trails and on 6 of 30 surveyed campsites. Over 95% of spotted knapweed along the trails occurred within 0.31 mile of the trailhead and within 15 ft of the trail. (Marcus and others 1998).

Trail Effects on Wildlife—A number of recent empirical studies examined wildlife disturbance caused by recreational use of trails. The first group of studies investigated community composition and wildlife behavior in relation to trails. The existence of a trail network can act as a barrier or attraction to different wildlife species. In northwestern Montana, grizzly bears were found to avoid roads and trails (Kasworm and Monley 1990). In a Colorado recreational area, Miller and others (1998) found that generalist bird species were more abundant near trails, while specialist species were less common. Higher nest predation rates were also recorded near trails (Miller and others 1998). Visitors hiking on trails may disturb wildlife, displacing them from trail corridors during times of heavy use (temporal displacement) or permanently (spatial displacement). Knight and Cole (1995) reviewed research that documented highly variable wildlife responses to the presence of visitors, depending on the visitors' behaviors, the context of the disturbance and the wildlife's learned responses.

The second group of studies utilized an experimental approach to examine human disturbance related to trail use. In the Medicine Bow National Forest, Wyoming, Gutzwiller and others (1998) identified variations in avian response to an experimental walker. Intrusion tolerance was found to be lower when birds were in smaller groups, for more conspicuous species, and for species that are active closer to the ground (Gutzwiller and others 1998).

Results from these two groups of trail-wildlife studies suggest that trails and their visitors have the potential to generate undesirable impacts on wildlife from population to ecosystem levels, with significant implications for biodiversity conservation (Cole and Knight 1990).

Trail Impact Assessment and Monitoring—Trail impact assessment studies have been conducted in both Eastern and Western environments over the past decade. In Great Smoky Mountains National Park, a census-based problem assessment method identified the locations, extent, and frequency of selected trail impact problems (Leung and Marion 1999a; Marion 1994a). Subsequent work at this Park and an ongoing study in Shenandoah National Park compare the problem-oriented survey approach to the more traditional point sampling approach (Leung and others 1997). The point sampling method provides a lineal sequence of values typically assessed at a fixed interval along the trail, summarized with descriptive statistics (such as range, mean, median). The problem assessment method characterizes trail conditions by providing statistics such as number and location of occurrences, feet/mile, percent of trail length and aggregate distance for predefined trail impact problems. Preliminary observations suggest that the higher utility of this type of data for managers may be offset by reduced precision, a result of inherent subjectivity in defining and assessing where impact problems begin and end along a trail.

Cole replicated his earlier trail assessment (Cole 1983) in the Selway-Bitterroot Wilderness. Over an 11-year period, the monitored trail systems remained relatively stable, with cross-sectional area measurements revealing virtually no net erosion or deposition on tread surfaces. Individual sections did change markedly, primarily influenced by trail location and design. Tread width increased an average of 9.8 inches over a nine-year period, but bare width did not change significantly. In Rocky Mountain National Park, Summer reported that the degree of soil erosion and deposition was primarily a function of active geomorphological processes interacting with climatic factors (Summer 1986). Steep, upper-slope trail positions were most erodible. Intermediate positions experienced both erosion and deposition; and level terrain was most stable, though trail widening was problematic. Intensive runoff from natural events was cited as a more significant cause of erosion than visitor use.

Camping-Related Impacts

Campsites are primary destinations for many wilderness visitors and receive high levels of use. In contrast to trail studies, most campsite studies were conducted in the U.S., and many were conducted in designated wildernesses (Figure 2). Earlier studies on campsite impacts have been reviewed by Cole (1987b). Recent research has focused on: (1) understanding previously ignored topics of impacts (Zabinski and Gannon 1997), (2) examining the effectiveness of site restoration techniques (Spildie and others, this volume), (3) improving assessment and monitoring procedures (Cole 1989d; Leung and Marion 1999b; Marion 1991), and (4) adapting procedures to new environments and recreation settings (Monz 1998).

Soil and Vegetation Impacts—Camping activities can generate substantial and usually localized soil and vegetation changes (McEwen and Cole 1997). Most studies have found high levels of groundcover loss and soil exposure even with modest use (Cole 1986). For example, in Prince William Sound of Alaska, low-use campsites lost 93% of their vegetation cover on gravel sites and 81% on organic soil sites (Monz 1998). An experimental camping study conducted by Cole (1995a) found that one night of camping activity caused significant groundcover loss in all four vegetation types examined. In more heavily used wilderness areas, such as Shining Rock Wilderness in North Carolina, frequent camping use often results in extensive land disturbance and vegetation damage (Saunders 1986).

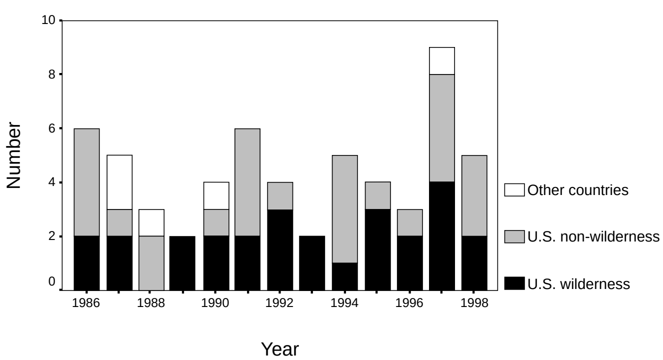

Figure 2—The numbers of publications on campsite impacts between 1986 and 1998 (based on the literature that was available to the authors when this paper was prepared).

Little research has been conducted on recreation impacts to soil microbial communities and underground processes (Cole and Landres 1996). Zabinski and Gannon (1997) examined this issue and reported less microbial activity in the upper layer (0-2.4 in) of soil on campsites than on their undisturbed controls, although there was no significant difference in the lower soil layer (2.4-6.8 in). The percentage of total carbon sources utilized by soil microbes was also significantly less in disturbed camping areas than in undisturbed control sites (Zabinski and Gannon 1997).

While camping impacts are usually spatially concentrated, some forms are more extensive. Taylor investigated 30 campsites in Yellowstone National Park and found that tree sapling density on campsites was only one-eighth that on control sites, which were located 160 ft from camp (Taylor 1997). Such decreases in tree saplings due to recreational use have a significant implication on tree regeneration and future forest structure.

Using a modeling approach, Cole (1992) examined the relative influence of use-related and environmental factors in determining the total amount of campsite impact. He demonstrated that degree of activity concentration is the most important factor. Several studies have documented the effectiveness of site locations and management actions that increase spatial concentration of use. In Great Smoky Mountains National Park, campsites at mid-slope topographic positions tend to be smaller than those on valley bottom or ridgetop positions, attributable to the site expansion resistance offered by sloping terrain (Leung and Marion 1999b). In the Chisos Mountains of Big Bend National Park, Texas, placement of campsite posts and logs to mark indistinct campsite borders have helped concentrate visitor activities within core use areas (Williams and Marion 1997). Median campsite size for these designated sites was only 650 ft^2. Similarly, the placement of many Isle Royale National Park campsites in sloping terrain, coupled with design and construction practices that create small flat camping benches, reduced median campsite size to 550 ft^2 (Farrell and Marion 1997). Camping shelters were even more effective in concentrating camping activities, with a median area of disturbance of 377 ft^2.

Other environmental factors, including elevation, aspect and plant community type, have also been investigated. Analyses of the influence of elevation on campsite conditions in Shenandoah and Great Smoky Mountains National Parks found no significant relationships with campsite size, vegetation loss or exposed soil (Williams and Marion 1995; Marion and Leung 1997). Campsites in Shenandoah National Park with a northerly aspect had more onsite vegetation cover and less than one-third the areal loss of vegetation cover than those with other aspects; no patterns were found in similar analyses at Great Smoky Mountains National Park. Analyses of forest cover type at Shenandoah National Park found that the chestnut oak and northern red oak forest types generally had the smallest and least altered campsites (Williams and Marion 1995). Campsites in the hemlock type were largest and had the least onsite vegetation cover at Great Smoky Mountains National Park (Marion and Leung 1997). Hemlocks have particularly dense canopies that support limited ground vegetation, so expansion potential is often high while trampling resistance is low. Evaluations of forest canopy densities consistently reveal a positive relationship between decreasing canopy density and increasing onsite vegetation groundcover (Marion 1994b; Marion and Leung 1997; Williams and Marion 1995). This finding is attributed to the higher trampling resistance and resilience of shade-intolerant grasses and herbs.

Very little recent work has examined use-related factors. An experimental camping study by Cole (1995a) found that one night of camping reduced relative vegetation height by 60% or more. Relative vegetation cover was reduced to as low as 66% following only one night of camping in four vegetation types. The impact associated with three additional nights of camping was less substantial, further reducing relative cover to only 50%. Results from this study generally corroborate those of earlier studies (Cole 1987b) that describe a curvilinear use-impact relationship.

McEwen and others (1996) investigated differences in impact from two types of use on campsites in four south-central U.S. wildernesses. Sites used by horse groups and hikers were more highly impacted than sites used only by hikers. Specifically, horse-hiker sites were larger and had more exposed soil and more tree damage than hiker-only sites.

Camping-Related Wildlife Impacts—Visitors spend considerable time on campsites, and their activities can disrupt normal wildlife activities, attract animals or alter wildlife habitat through vegetation and soil impacts. Wildlife that avoid areas with campsites can be displaced from vital riparian vegetation and water sources, a particularly critical impact in desert environments (Hammitt and Cole 1998). Intentional or unintentional wildlife feeding is also common at campsites, leading to attraction behavior and unhealthy food dependencies. Species that frequent campsites in search of food include birds, mice, rats, ground and red squirrels, skunks, racoons, foxes and bears. Consistent human feeding can lead to increases in small animal populations, which then crash suddenly at the end of the use season. Bears that obtain food pose a serious safety threat to visitors, and many must be relocated or killed (Merrill 1978).

Campsite Impact Assessment and Monitoring—Campsite impact assessment and monitoring programs are generally more common than trail assessments, and a large number have been conducted in the past decade. The campsite monitoring program in Kings Canyon and Sequoia National Parks of California is one of the earliest and best documented of its kind (Parsons 1986; Parsons and Stohlgren 1987; Stohlgren and Parsons 1986; Stohlgren and Parsons 1992; van Wagtendonk and Parsons 1996). Over 8,000 sites had been assessed as of 1990 (Fodor 1990). Published accounts of assessment programs are also available for wildernesses and national parks in Arizona (Cole and Hall 1992), Montana (Cole 1993a; Cole and Hall 1992), Oregon (Cole and Hall 1992; Cole and others 1997), Washington (Cole and others 1997; Gettinger and others 1998; Rochefort and Swinney, this volume; Scott 1998), Michigan (Farrell and Marion 1997), North Carolina/Tennessee (Leung and Marion 1999b; Marion and Leung 1997; Marion and Leung 1998), Virginia (Williams and Marion 1995), Texas (Williams and Marion 1997), and Illinois/Missouri/Arkansas (McEwen and others 1996).

Studies of trends in campsites (Cole and Hall 1992) monitored for 5 to 11 years in three Western backcountry areas found that campsites both improved and degraded over time. Campsite size, mineral soil exposure and tree damage were some of the impacts that increased (Cole and Hall 1992). In three Western wildernesses, Cole (1993a) found that the number of campsites increased 53% to 123% over 12 to 16 years. Campsite proliferation contributed more to net increase in the total amount of impact than change in the condition of existing campsites (Cole 1993a).

Trampling Research

Trampling, either by humans or recreational stock, is the fundamental impact force applied to trails and campsites, directly affecting vegetation and soil within trampled zones. Although often localized, trampling may have widespread effects. The extirpation of Scarbrous black sedge (*Carex atratiformis*), northern singlespike sedge (*Carex scirpoidea*) and other alpine plant species in the New England region (Zika 1991) and the decline of endangered desert fish populations in Zion National Park of Utah (Shakarjian and Stanford 1999) have been attributed to human trampling. Research on trampling and traffic effects on soil and vegetation have recently been compiled and reviewed (Yorks and others 1997).

Several trampling experiments were conducted in wilderness and backcountry areas in the past decade. Cole continued his earlier work (as reviewed by Cole 1987b) on six forest and grassland vegetation types in the Bob Marshall Wilderness complex (Cole 1987a; Cole 1988). He expanded his studies to 16 vegetation types in four Western and Eastern states (Cole 1993b; Cole 1995b; Cole 1995c). Using standardized experimental procedures, he compared vegetation types by their differential responses to foot trampling. The relationship between trampling intensity and vegetation damage was curvilinear in most cases, corroborating previous research (Figure 3). Resistant vegetation types, such as sedges (*Carex* spp.), were found to be able to absorb 25 to 30 times as much trampling as the least resistant type, ferns (*Dryopteris* spp.) (Cole 1993b). Morphological characteristics were the primary factor influencing plant resistance to trampling. Grasses and sedges have flexible stems growing in mats or tufts. More fragile were woody plants and taller herbs.

The resilience of plants, their ability to recover following trampling disturbance, varied substantially by habitat, with higher recovery in the most productive environments—those with higher soil fertility and moisture. For example, recovery rates are high in riparian areas in the Eastern states (Cole and Marion 1988; Marion and Cole 1996). In contrast, trampling impacts in less resilient environments, such as alpine and subalpine environments, require a long time to recover (Hartley 1999; Stohlgren and Parsons 1986). Plant characteristics, notably the position of the plants' perennating bud and physiological characteristics such as reproductive capacity and growth rates, also influence resilience (Cole 1988; Kuss 1986b).

In the wind River Range of Wyoming, trampling response of five native plant species was examined (Monz and others 1994). Increased trampling intensities were associated with substantial increases in soil compaction and decreases in species richness at forest understory sites. Little effect was

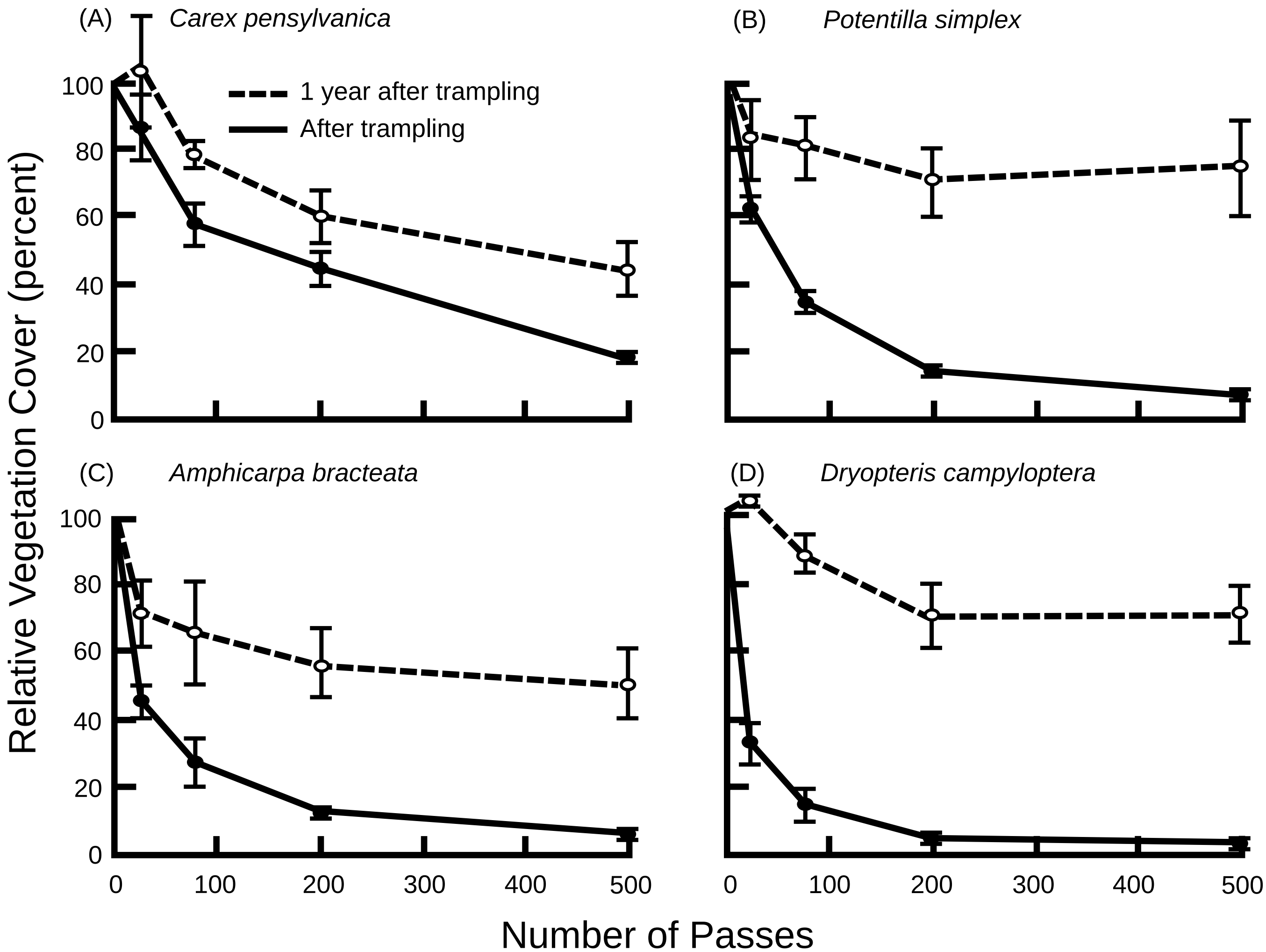

Figure 3—Relationships between trampling intensity and relative groundcover in four vegetation types in the Great Smoky Mountains, North Carolina. Bars denote one standard error (Source: Cole 1993b).

found on subalpine meadows. More recently, Monz and others (1996) examined trampling and increased temperature on moist and dry arctic tundra. Moist tundra was found to be highly susceptible to trampling disturbance, though warmer temperatures resulted in decreased leaf nitrogen, increased percent cover and increased number of leaves in mountain-aven (*Dryas octopetala*) (Monz and others 1996).

Hartley conducted a long-term study of trampling effects and recovery in the subalpine meadows of Glacier National Park, Montana (Hartley 1999). Thirty years after trampling was first applied in 1967, he reported significantly shorter inflorescence heights of fleabane (*Erigeron*) and significantly lower densities of both yellow avalanche-lily (*Erythronium* spp.) and fleabane (*Erigeron* spp.) within trampled plots than in control plots. As has been reported elsewhere (Kuss and Hall 1991; Weaver and Dale 1990), recovery of trampling impacts can be exceptionally slow in less resilient environments.

Cole investigated trampling effects on cryptogamic soil crusts in Grand Canyon National Park (Cole 1990b). He found that cryptogamic soil crusts, which are ecologically important features in arid ecosystems, are fragile and extremely susceptible to trampling impact. Crust structure damage was caused by only 15 trampling passes. Complete loss of crust cover occurred after 250 passes (Cole 1990b). de Gouvenain (1996) examined indirect effects of soil trampling on plant growth in the northern Cascade Mountains, Washington. He reported significantly higher soil water content and temperature on trampled sites, which may have influenced long-term plant succession in the study area (de Gouvenain 1996).

Cole conducted trampling experiments to evaluate two recommended LNT practices: removing boots and the use of a geotextile ground cloth in camp. His results showed that these two practices have small short-term benefits but no long-term benefits (Cole 1997).

Recent increases in popularity of llamas and other nontraditional pack stock have generated research interest in their relative trampling effects (McClaran and Cole 1993). DeLuca and others (1998) compared the effects of llamas with horses and hikers on soil erosion and found that horse traffic produced significantly higher sediment yield from established forest trails in Montana than either llama or hiker traffic, which did not significantly differ from each other.

Cole and Spildie (1998) also found greater trampling impact on vegetation by horses than by llamas or humans.

Other Types of Recreation Impact Research

Effectiveness of Management Actions—There have been few but increasing numbers of trail and campsite studies that investigate the effectiveness of impact management strategies and actions. The placement of scree walls along trail boundaries, for instance, was reported to be effective in containing hikers and associated trampling impacts within trail treads (Doucette and Kimball 1990). Marion (1995) provides a detailed case study of management success in Delaware Water Gap National Recreation Area in Pennsylvania. Two major management actions were the designation of campsites and the provision of anchored fire grates. Together with supporting actions, these management efforts effectively reduced aggregate camping-induced land disturbance by more than 50 percent between 1986 and 1991, even with modest increases in visitation (Marion 1995).

A management program recently adopted in Idaho's Selway-Bitterroot Wilderness also demonstrates the effectiveness of a spatial containment strategy (Spildie and others, this volume). A coordinated set of management actions, including: (1) designation of stock containment areas, (2) closure of some sites to stock use or all use, and (3) intensive site restoration. In five years, the areal extent of recreation disturbance was reduced by 37 percent, and bare soil was reduced more than 40 percent. Designated camping policies and site restoration actions were also found to be effective in the Boundary Waters Canoe Areas Wilderness, Minnesota (Marion and Sober 1987).

Attempts to restore impacted sites have been less effective, however. In Yosemite National Park of California, efforts to restore bare core areas on degraded high-elevation campsites by transplanting vegetation met with only modest success. Three years after program initiation, species richness and percent plant cover increased only slightly and the survival rate of transplants was low (Moritsch and Muir 1993). A 1998 study of these same campsites found that plant re-establishment was substantial on campsites with higher soil moisture, while recovery on dry sites was low (Eagan and Newman 1999). Some success with soil amendments and planting techniques as a means of speeding recovery rates was recently reported from the Eagle Cap Wilderness (Cole, this volume).

Impact Indicators for Management Frameworks—As input to management planning frameworks such as LAC and VERP, a diverse array of resource and impact indicators and their utility have been reviewed (Merigliano 1990; Watson and Cole 1992). Belnap (1998) investigated steps for selecting resource indicators in Arches National Park, Utah, as part of the Park's VERP planning and implementation process. Based on a list of selection criteria and a ranking system, she selected eight resource and impact indicators to define the health of this arid ecosystem. Indicators were assigned to two categories, one requiring measurements every year, and another requiring measurements every five years (Belnap 1998).

Setting standards for recreation impacts is another emerging issue with little research and management attention. A recent survey of trail managers found that condition standards for backcountry trails were either lacking or poorly defined in the parks studied (Burde and others 1998). With increasing adoption of management frameworks in wilderness and backcountry areas, research in this area is much needed.

Packstock Grazing Impact—The impact of packstock grazing and recovery processes were the subject of two pack horse grazing studies in subalpine meadows within the Lee Metcalf Wilderness of Montana (Olson-Rutz and others 1996a; Olson-Rutz and others 1996b). The grazing behavior of horses was quantified and related to the intensity and extent of impact. Results indicated that increased grazing duration was associated with reduced plant heights, and that grass heights appeared to be reduced more than forb heights (Olson-Rutz and others 1996a). One year after the pack horse grazing, more bare ground and less litter and vegetative cover were recorded, attributed to reduced stem numbers (Olson-Rutz and others 1996b). Research on packstock grazing impact on meadows is currently being conducted in Yosemite National Park (van Wagtendonk and others, this volume).

Climbing—Rock climbing is rapidly growing in popularity. Potential climbing-related impacts, including trail creation and use in steep approach areas, cleaning of vegetation and lichens from cliff faces, and use of protective hardware such as expansion bolts, have received little research attention until recently (Attarian and Pyke 2000). Earlier studies focused primarily on the proliferation of social trails and trampling of climbers in the access zone at the base of cliffs (Genetti and Zenone 1987). More recent studies have turned their attention to the cliff plant and wildlife communities on the vertical climbing zone. In Joshua Tree National Park of California, cliffs used intensively for climbing were found to have the lowest richness of cliff plant communities, and the number of individual plants and plant cover decreased with increased level of use (Camp and Knight 1998). Other studies in nonwilderness areas also found significant impact on vegetation and microflora (Nuzzo 1995; Nuzzo 1996).

Human Waste—The problem of improper human waste disposal is a perennial concern among wilderness managers (Cilimburg and others 2000). In Mount Rainier National Park of Washington, up to 10,000 climbers visit the summit of Mount Rainier each year, raising the possibility of fecal contamination in high-elevation areas such as the Muir Snowfield. An initial investigation was conducted recently to determine if surface water runoff from the snowfield was contaminated by fecal microorganisms such as fecal coliforms, fecal streptococci, fecal enterococci and E. coli (Ells 1997). Results indicated no significant evidence of contamination. Cilimburg and others (2000) provide a comprehensive review of the human waste disposal problem and management options.

Management Responses and Related Research

The identification and selection of effective management techniques requires knowledge of the impacts that are occurring, their underlying causes and the role of various influential factors. The research described in the preceding section should be integrated with current monitoring data and management expertise in a careful problem analysis prior to the identification and selection of management strategies and actions.

Management Needs and Constraints

Faced with a limited wilderness resource base and increasing recreational demands, managers must decide how much and what kinds of recreation use are acceptable, recognizing that any visitation generates some degree of resource impairment. They must explicitly define when visitation-related environmental change becomes an unacceptable impact, requiring management intervention. Research and monitoring can inform such decisions, but managers must make them, preferably in consultation with the public.

The Wilderness Act (P.L. 88-577) defines wilderness as "undeveloped" lands "without permanent improvements" which "has outstanding opportunities for solitude or a primitive and unconfined type of recreation," and where "the imprint of man's work is substantially unnoticeable." Furthermore, it states that "except as necessary to meet minimum requirements for the administration of the area...there shall be no...motorized equipment...and no structure or installation within any such area." In light of this mandate, managing agencies have generally adopted what has become known as the *minimum tool rule* to guide their wilderness management actions (Hendee and others 1990). This rule directs managers to apply only the minimum tools, equipment, device, force, regulations or practice that will accomplish the desired result.

This guidance is frequently interpreted as a need to first select and attempt indirect management actions, such as Leave No Trace educational practices or improved trail and site design and maintenance before more direct controls such as regulations. However, if indirect methods fail to resolve resource protection problems, managers must be prepared to apply more restrictive measures. It has been argued that managers must not hesitate to employ direct controls, even as initial actions, when long-term or irreversible resource degradation is occurring (Dustin and McAvoy 1982).

Decisions about the use of site hardening and facility development actions in wilderness are particularly difficult. A constructed and maintained trail is a permanent wilderness facility designed both to facilitate wilderness travel and protect resources. Such facilities can involve vegetation disturbance, soil excavation and deposition, and the potential disruption of surface water movement. However, a properly managed trail system limits the areal extent and severity of recreation impacts by concentrating traffic on resistant tread surfaces. The absence of formal trails in popular locations would lead to a proliferation of poorly located and heavily impacted visitor-created trails. Similarly, although less common in wilderness, designated campsites can be located, constructed and maintained to substantially reduce the areal extent and severity of camping impacts. The Wilderness Act clearly permits managers to employ such facilities, although their use must be justified as the minimum means for managing sustainable visitation.

Management Strategies and Tactics

Recreation impact problems may be addressed through an array of management strategies and tactics (Anderson and others 1998; Brown and others 1987; Cole and others 1987; Hammitt and Cole 1998; Hendee and others 1990; Leung and Marion 1999d). The following discussion follows the strategies and tactics described by Cole and others (1987) (Table 6).

Management interventions seek to avoid or minimize recreation impacts by manipulating either use-related or environmental factors. Use-related factors, particularly the redistribution or limitation of visitor use, have received more research and management attention. However, research has increasingly demonstrated the importance of environmental factors, such as focusing use in environmentally resistant locations or increasing resource resistance through the use of facilities like trails and campsites (Cole 1990a). The modification of visitor behavior through educational and regulatory actions is another frequently applied strategy.

Modification of Use-Related Factors—Managers can control or influence amount of use, density of use, type of use, and user behavior. The type of visitor action contributing to the management problem is often an important consideration (Cole 1990a). For example, impacts from visitors knowingly engaging in illegal actions require a law enforcement response. Careless, unskilled or uninformed actions are often most appropriately addressed through visitor contacts and educational responses (Lucas 1982). Unavoidable impacts are commonly reduced by relocating visitation to resistant surfaces or by limiting use.

1. Amount of Use: Amount of use is perhaps the most studied use-related factor in recreation ecology. Earlier studies have consistently found a nonlinear asymptotic relationship between amount of use and amount of impact (Cole 1987b). Most forms of camping impact occur rapidly with initial and low levels of use (up to 10 nights/year), then begin to level off as near-maximum impact levels are reached at moderate to high use levels. This use-impact relationship has been corroborated by recent trampling studies for most impact parameters with a few exceptions (such as exposure of mineral soil) (Cole 1987a; Cole 1988; Cole 1990b; Cole 1993b; Cole 1995b; Cole 1995c; Cole and Trull 1992; Kuss and Hall 1991).

The curvilinear use-impact relationship reduces the potential effectiveness of use limitation for reducing recreation impacts (Strategies I & II, Table 6). Substantial use reductions would be necessary to achieve even modest improvements in resource condition on heavily impacted trails and campsites. However, use reductions can lead to pronounced improvements at lower use levels, where use and impact are more strongly related (although slow recovery rates prevent rapid improvements) (Cole 1995a). Also, limitations on the number of groups, particularly during times of peak use (Strategy IV), can reduce the total area of camping disturbance by shrinking the number of campsites needed. For example, a popular travel zone may receive over twice the

Table 6—Strategies and tactics for managing recreation impacts to resources or visitor experiences.

I. Reduce use of the entire area
- Limit number of visitors in the entire area
- Limit length of stay in the entire area
- Encourage use of other areas
- Require certain skills and/or equipment
- Charge a flat visitor fee
- Make access more difficult throughout the entire area

II. Reduce use of problem areas
- Inform potential visitors of the disadvantages of problem areas and/or advantages of alternative areas
- Discourage or prohibit use of problem areas
- Limit number of visitors in problem areas
- Encourage or require a length-of-stay limit in problem areas
- Make access to problem areas more difficult and/or improve access to alternative areas
- Eliminate facilities or attractions in problem areas and/or improve facilities or attractions in alternative areas
- Encourage off-trail travel
- Establish differential skill and/or equipment requirements
- Charge differential visitor fees

III. Modify the location of use within problem areas
- Discourage or prohibit camping and/or stock use on certain campsites and/or locations
- Encourage or permit camping and/or stock use only on certain campsites and/or locations
- Locate facilities on durable sites
- Concentrate use on sites through facility design and/or information
- Discourage or prohibit off-trail travel
- Segregate different types of visitors

IV. Modify the timing of use
- Encourage use outside of peak use periods
- Discourage or prohibit use when impact potential is high
- Charge fees during periods of high use and/or high-impact potential

V. Modify type of use and visitor behavior
- Discourage or prohibit particularly damaging practices and/or equipment
- Encourage or require certain behavior, skills and/or equipment
- Teach a wilderness ethic
  Encourage or require a party size and/or stock limit
- Discourage or prohibit stock
- Discourage or prohibit pets
- Discourage or prohibit overnight use

VI. Modify visitor expectations
- Inform visitors about appropriate uses
- Inform visitors about conditions they may encounter

VII. Increase the resistance of the resource
- Shield the site from impact
- Strengthen the site

VIII. Maintain or rehabilitate the resource
- Remove problems
- Maintain or rehabilitate impacted locations

Source: Cole and others (1987).

visitation on peak use weekends than it does during more typical high use periods. Use can also be limited during times when resources are more vulnerable to impact, by restricting horse traffic when trails are particularly wet, for example. Tactics for rationing use are reviewed in Anderson and others (1998), and Cole and others (1987).

2. Density of Use: How much visitation is concentrated spatially affects both the areal extent and severity of resource impacts (Marion and Cole 1996). Educational programs and regulations may be used to shape visitation density, generally through one of two strategies: visitor dispersal, which spreads use sufficiently to avoid or minimize long-term impacts, and visitor containment, which concentrates use to limit the areal extent of impact (Cole 1981; Cole 1992; Leung and Marion 1999d). Containment, as evidenced by the development and maintenance of formal trail systems, has a long tradition of use in wilderness. Its application to camping management is less common, but a variety of options are now in use (Marion, Roggenbuck and Manning 1993). In contrast, dispersal is rarely applied to reduce hiking impacts except for remote low-use areas. Its application to camping management is more common, although many factors thwart the success of this strategy.

When camping is unregulated, visitors are free to choose any existing campsite or create new ones. This policy can result in many poorly located campsites (Cole 1993a; Leung and Marion, this volume; McEwen and others 1996). For example, wilderness campsites in the Jefferson National Forest of Virginia were frequently located on trampling-susceptible herbaceous groundcover in areas that readily permit site expansion and proliferation (Leung and Marion, this volume). Campsites were also located close to trails and other campsites, enhancing the potential for visitor conflicts and reducing solitude for both campers and hikers.

A successful application of dispersal and containment strategies can reduce camping impacts. Consider three campsites that receive intermediate amounts of use (10-20 nights/year) under an unregulated camping policy (Figure 4). Aggregate resource impact for these sites would be three times the "a" amount of impact. Under the purest form of dispersed camping, these sites would be closed and their use distributed across 45 pristine sites, each receiving only one night of use/year. Most vegetation types can sustain such light camping with no permanent impact visible the following year. More resistant surfaces, like grassy groundcover, sand, gravel and rock, can accommodate many more nights of use without permanent impact. The

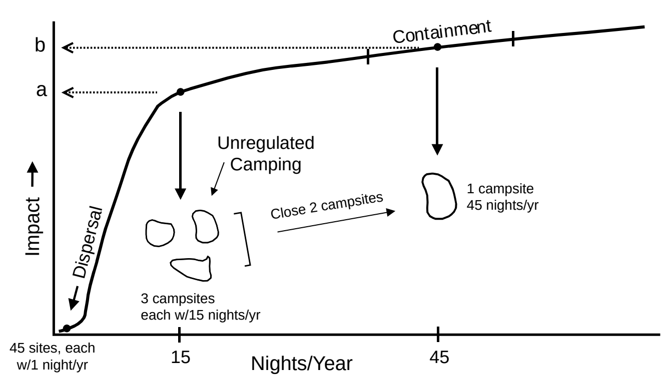

Figure 4—A generalized use-impact curve illustrating the intended locations of typical or average campsites under dispersal and containment strategies.

low camping densities under a dispersal strategy also resolve problems with crowding and conflicts.

In contrast, a containment strategy could be implemented by closing two of the three original sites and distributing their use to the third. Due to the curvilinear use-impact relationship, impact on this third site would increase only marginally, from "a" to "b" (Figure 4). Aggregate impact would decline substantially, from three sites with an "a" level of impact to one site with a "b" level of impact. Application of this strategy was largely responsible for a 50 percent reduction in the total area of disturbance from river camping at Delaware Water Gap National Recreation Area (Marion 1995). Furthermore, in addition to favoring resistant sites, site selection criteria emphasized the closure of sites within dense clusters, addressing crowding and conflict problems by maximizing intersite distances.

While these strategies may seem straightforward, additional issues often complicate their implementation. Achieving the level of camping dispersal necessary to prevent impacts has proven exceptionally difficult. In most vegetation types more than a few nights of camping will quickly create lasting impacts—that is, permanent campsites (Cole 1995a). Mountainous topography, dense vegetation, and availability of water frequently limit the number of potential camping locations, and few of these contain resistant surfaces (Williams and Marion 1995). Furthermore, most visitors prefer camping on established sites close to trails, water and popular features (Lucas 1990a). Generally, a dispersed camping strategy will be effective only in areas that receive low levels of use, have numerous potential camping locations that are resistant and/or resilient, and where visitors are willing to learn and apply Leave No Trace camping practices (Cole 1981; Leung and Marion 1999d). Managers at Denali National Park and Preserve of Alaska have developed one of the most successful dispersed camping programs, although visitor use numbers are also highly restricted.

A successful containment strategy requires concentrating camping activities on the smallest number of sites needed to accommodate the intended level of use (Leung and Marion 1999d). Reserved, designated site camping permits the smallest number of campsites and aggregate impact. However, fixed itineraries are difficult to follow in wilderness and entail a substantial loss of visitor freedom (Stewart 1989). Designated site camping without a reservation system allows greater flexibility. Visitor use surveys can provide information for matching campsite numbers and locations to visitor use patterns, or entry point quotas can restrict use based on available campsite numbers (Lime and Buchman 1974). To avoid excessively large inventories of campsites, use surveys should be conducted during average high use periods rather than peak use periods. In comparison to areas with site reservation systems, somewhat larger numbers of campsites are necessary to avoid the "musical chairs" dilemma of too many visitor groups and too few campsites. An educational approach, asking visitors to camp only on well-established campsites, may also be used (Cole and Benedict 1983).

Some wilderness and backcountry areas have adopted multi-strategy camping policies (Leung and Marion 1999d). New backcountry camping management policies at Shenandoah National Park provide an example (National Park Service 1998). A few areas containing sensitive cultural and natural resources or that accommodate high day use will be closed to camping. In high-use areas, visitors will be required to camp on a limited number of designated campsites on a first-come, first-served basis. In remaining areas, visitors will be asked to camp on well-established campsites, a limited number of which will be selected by managers for resistance and ability to promote solitude. Dispersed camping on pristine sites will be permitted when all available campsites are used. While more complex, such combined strategies offer substantial flexibility in balancing wilderness resource protection and recreation provision objectives.

3. Type of Use: Types of uses that result in greater or disproportionate impacts are often subject to special regulations or educational programs (Strategy V). For example, visitors with horses have been restricted to a subset of more resistant trails and campsites specifically selected and maintained to sustain such use. While large groups create larger campsites than small groups, splitting them up may require more campsites and an equivalent amount of aggregate impact (Cole 1987b; Cole and Marion 1988). Matching group size with site size is therefore a significant management challenge. Further research on the relationship between party size and resource impact is needed.

4. User Behavior: Many impacts are avoidable, often caused by uninformed or careless behavior (Lucas 1982). Managers can educate and regulate visitors to avoid or reduce visitor behavior that contributes to avoidable impacts (Strategy V). The most common avoidable resource impacts include littering, cutting switchbacks, creating new trails and campsites, trail widening and campsite expansion, moving or building new fire sites, improper disposal of human and food waste, wildlife and cultural resource disturbance and cutting trees or tree limbs. Management efforts can also target many unavoidable impacts, such as vegetation disturbance and soil compaction caused by foot traffic. A variety of low-impact hiking and camping practices have been described to address these impacts (Cole 1989b; Hampton and Cole 1995), along with alternative education techniques for conveying such practices to visitors (Doucette and Cole 1993).

The four federal wilderness management agencies in partnership with the National Outdoor Leadership School have founded and actively promote a national *Leave No Trace* program that teaches outdoor ethics and low impact hiking and camping practices (Hammitt and Cole 1998; Marion and Brame 1996). *Leave No Trace* training courses, publications and a comprehensive web site (http://www.LNT.org) are now reaching millions of potential wilderness visitors. Agency wilderness-specific educational contacts, signs and materials reinforce this effort and target specific problems.

Although more restrictive to visitor freedom and experiences, regulations offer another option for altering visitor behavior to reduce impacts (Lucas 1982). For example, regulations requiring proper food storage or fines for visitors who feed wildlife can help return wildlife to natural diets. Generally, regulations should only be used when indirect options are likely to be ineffective (Lucas 1990b). Interventions may employ both educational and regulatory responses. For example, excessive tree damage may be addressed by instructing campers to use stoves or to build small fires using dead down wood that can be broken by hand. A regulation prohibiting axes, hatchets and saws removes the unnecessary tools most commonly used to damage trees.

Modification of Environmental Factors—Managers can also influence or control the location of visitor use in wilderness (Strategy III) and manage the trails and campsites that sustain that use (Strategies VII and VIII). For example, trails may be designed to avoid areas prone to muddiness, fragile vegetation types and steep slopes or erodible soils. Camping may be encouraged in durable vegetation types. Trail and campsite impacts can be reduced through careful site selection, design, construction and maintenance.

1. Environmental Resistance: Previous research has demonstrated considerable variability in the trampling resistance of different vegetative growth forms and plant communities (Cole 1987b; Kuss 1986b; Liddle 1991). Resistant plant communities and environments may be targeted for camping, while fragile communities may be avoided or identified for closures to camping. Examples of resistant plant communities include dry open forests and meadows with substantial grass or sedge cover, dense forests with little or no vegetation cover and sand, gravel and bedrock substrates.

Soils also vary in their resistance to compaction and erosion. Moist soils with little organic matter and a wide range of particle sizes (such as loams) are the most prone to compaction, while soils with a narrow range of particle sizes, particularly those high in silt and fine sands, are most prone to erosion (Hammitt and Cole 1998; Kuss and others 1990). Both soil compaction and erosion are accelerated by the absence of vegetation and organic litter, and slope is a critical determinant of erosion potential.

Wilderness managers can do little to modify environmental resistance. However, the construction and use of trails and campsites frequently opens forest canopies, allowing greater sunlight penetration and enhancing the survival and spread of shade-intolerant, trampling-resistant grasses, sedges and herbs. Seeding and transplanting resistant vegetation, using locally obtained sources of native plant materials, have been done in some wildernesses, and there is guidance for site restoration methods (Hanbey 1992). Although most commonly applied to closed campsites, many of these techniques have been employed by managers of the Boundary Waters Canoe Area Wilderness to reduce the size of open campsites (Marion and Sober 1987).

2. Environmental Resilience: Knowledge of the relative resiliency (ability to recover) of different vegetation and soil types may also be used to direct camping to areas that will recover quickly after trampling disturbance. However, impact rates are far greater than recovery rates, so off-season resource recovery is generally minimal and rest-rotation schemes to minimize impact are not warranted (Cole and Ranz 1983; Marion and Cole 1996). Environmental resilience can be an important consideration in low-use areas where dispersed hiking and camping are promoted (Cole 1995c). In more popular areas, the concentration of visitor activities is often sufficient to permanently remove most of the vegetation cover on trails and campsites. However, highly resilient vegetation still helps to restrict the size and further expansion of disturbance in these areas.

3. Site Management: Wilderness trails and campsites have rarely been planned and developed after careful evaluation of their expected ability to sustain use with minimal impact. Most wilderness managers simply inherit an inventory of trails dating back to earlier uses as Indian and settler travel ways, fire fighting roads and trails, logging roads and informal visitor-created trails. Similarly, most campsites, even those formally designated, were originally visitor-created. Examples abound of poorly located trails and campsites that are severely degraded. However, knowledge is now available to direct visitors to trails and campsites able to sustain heavy recreational traffic with far less resource impact than many existing recreation facilities. When necessary, site development that includes primitive facilities and sound maintenance can also contribute substantially to the avoidance and minimization of recreation impacts in wilderness.

Site Selection and Development—Knowledge of the environmental resistance and resilience of vegetation and soil types can be applied to select new and relocated trails and campsites (Hammitt and Cole 1998). Management options include educating visitors to improve site selection, marking resistant sites to encourage their use and designating resistant sites (Leung and Marion 1999b). Topography and other environmental attributes such as rockiness and vegetation density can also be considered to select locations that minimize impact severity and area of disturbance. In the Chisos Mountains of Big Bend National Park, managers have carefully selected and designated campsites to resist site expansion and promote solitude. The mean site size for these campsites is only 686 ft^2 (Williams and Marion 1997).

Managers at Isle Royale National Park have constructed campsites in sloping terrain, using standard cut-and-fill practices to create small benches for tenting and cooking areas (Farrell and Marion 1997). Camping posts and embedded logs or rocks are used in flat terrain to identify intended use areas and discourage site expansion. Managers can spatially arrange the sites to promote solitude and to minimize trail development to water sources and shared facilities like bear bag hanging devices and toilets (Hammitt and Cole 1998; Leung and Marion 1999d).

Site Maintenance—Trail maintenance programs exist in most wilderness areas, and many excellent manuals have been developed to guide this work (Birchard and Proudman 2000; Demrow and Salisbury 1998; Hesselbarth and Vachowski 1996). Active trail maintenance reduces impacts by providing a durable tread able to accommodate the intended traffic while minimizing problems with tread muddiness, erosion, widening and multiple tread development.

Much of the expertise gained in maintaining trails can be extended to maintaining campsites, although the appropriateness of such work in wilderness has been questioned (Cole 1990a). Maintenance work can reduce campsite sizes to the minimum necessary, prevent erosion and reduce campfire-related impacts (Hammitt and Cole 1998; Marion and Sober 1987). For example, excessive site size may be addressed by subtly improving tenting locations in core use areas (creating smooth, gently sloped areas) and ruining tenting locations in peripheral use areas. Site ruination work commonly includes “ice-berging” large rocks (burial except for sharp protruding tips), creating an irregular tenting surface by digging shallow scrapes and mounding soil and renaturalizing areas with large logs, organic debris and vegetative transplants. Such work should use native materials and be carefully blended to match natural conditions (Marion and Sober 1987). However, more artificial work may be justified in high-use areas or on particularly troublesome sites. Such work includes embedding rocks or logs to visually identify intended campsite boundaries or placing a camping post to attract and spatially concentrate visitor activities.

Site Facilities—Site facilities are not always visitor conveniences, and many serve important safety and resource protection functions (Cole 1990a). Bridges along trails are often built to safely transport trail users across deep or dangerous currents. Bridges also protect sensitive riparian areas from vegetation damage and soil erosion on steep slopes. Placement of small, firmly anchored steel fire rings can be used to identify preferred or legal campsites, spatially concentrate visitor activities to reduce site size and limit resource impacts by focusing fire-related activities at only one spot (Marion 1995). Pit toilets can resolve problems with improperly disposed human waste, particularly on high-use campsites where the volume of waste poses a threat to human health. Impacts from recreational stock can be concentrated by placement of stock restraint facilities.

Site Closures—Camping closures represent a final resource protection strategy, generally most appropriate for protecting sensitive environments, rare flora and fauna or fragile historic sites (Cole 1990a; Hammitt and Cole 1998). Camping closures around popular features such as waterfalls, cliffs, ponds and lakes may be appropriate to separate overnight campers from intensive day use. Closures of popular highly impacted campsites are often ineffective and inappropriate. Little recovery will occur unless all use is removed, and new campsites with greater aggregate impact are frequently created in nearby areas (Cole and Ranz 1983). Generally, such closures are warranted only when use is shifted from impact-susceptible locations to impact-resistant locations, although social considerations may also provide justification (Cole and Ranz 1983; Trafimow and Borrie 1999).

Impact Management Decisionmaking

Management of recreation impacts directly affects the quality of recreation resources and visitor experiences. For example, restricting camping to designated campsites may reduce campsite numbers and aggregate impact, but it also imposes a direct management "presence" and control on visitor freedom to travel and select campsites. Achieving an appropriate balance between the dual management objectives of resource protection and recreation provision frequently requires decisions that trade off recreation experience quality with natural resource quality. Such decisions are difficult and often controversial and must be defensible in both the court of public opinion and law.

A decision framework is simply a standard process that provides structure to decisionmaking for planning or management purposes (Hendee and Koch 1990). Historically, managers have relied on informal decisionmaking when addressing visitor impact issues. Common problems with this approach include a failure to explicitly describe intended resource or social conditions, evaluate the acceptability of existing conditions, conduct a thorough problem analysis or consider a comprehensive array of management alternatives (McCool and Cole 1997). Subsequent decisions may be indefensible and ineffective at restoring desired resource conditions.

The expanding popularity of wilderness recreation, greater public scrutiny of management decisionmaking and widening demands for participatory public land management are placing greater demands on land managers to further develop and communicate the processes by which decisions are made (Krumpe and McCool 1997). Formal decisionmaking frameworks have been developed and applied to guide both planning and operational decisions. These frameworks offer a defensible process for defining desired future resource conditions for visitor impact management, identifying impact indicators and assessing impact acceptability, conducting problem analyses, and evaluating and selecting preferred management actions.

Types of Frameworks

Formal frameworks may be simple or complex, as long as they identify and describe the steps by which decisions are made. Management constraints, such as limitations in funding, staffing and time, must be considered carefully in selecting the most appropriate framework. Recently, the most widely applied frameworks include *Limits of Acceptable Change* (LAC) (Stankey and others 1985) and *Visitor Experience and Resource Protection* (VERP) (National Park Service 1997a; National Park Service 1997b). These frameworks transform wilderness mandates into prescriptive objectives that can be implemented and evaluated with standards defining the limits of acceptable conditions for selected resource and social indicators (Figure 5). Monitoring permits periodic comparisons of conditions to standards. If standards are exceeded, a problem analysis evaluates causal factors to aid in selecting appropriate and effective management intervention(s). These models provide dynamic decision processes; future monitoring evaluates the success of implemented actions, so managers can select and implement additional actions if unacceptable conditions persist. Comprehensive reviews of these frameworks and their application to wilderness are provided in two state-of-knowledge reviews (Krumpe, this volume; Manning and Lime, this volume).

Decision frameworks require objective monitoring to characterize resource conditions for comparison to management objectives and/or indicator standards and to evaluate the success of implemented actions. Monitoring may be informal, such as staff observations or simple inventories, or formal, involving the application of standardized qualitative or quantitative procedures (Cole 1983; Cole 1989d; Marion 1991). Formal visitor impact monitoring programs employing quantitative ratings or measures are required for frameworks that use indicators and standards. Quantitative monitoring data can also be used to document trends in resource conditions, providing a permanent record of conditions that transcend changes in wilderness staff. Monitoring data may reveal subtle trends, alerting managers and allowing time

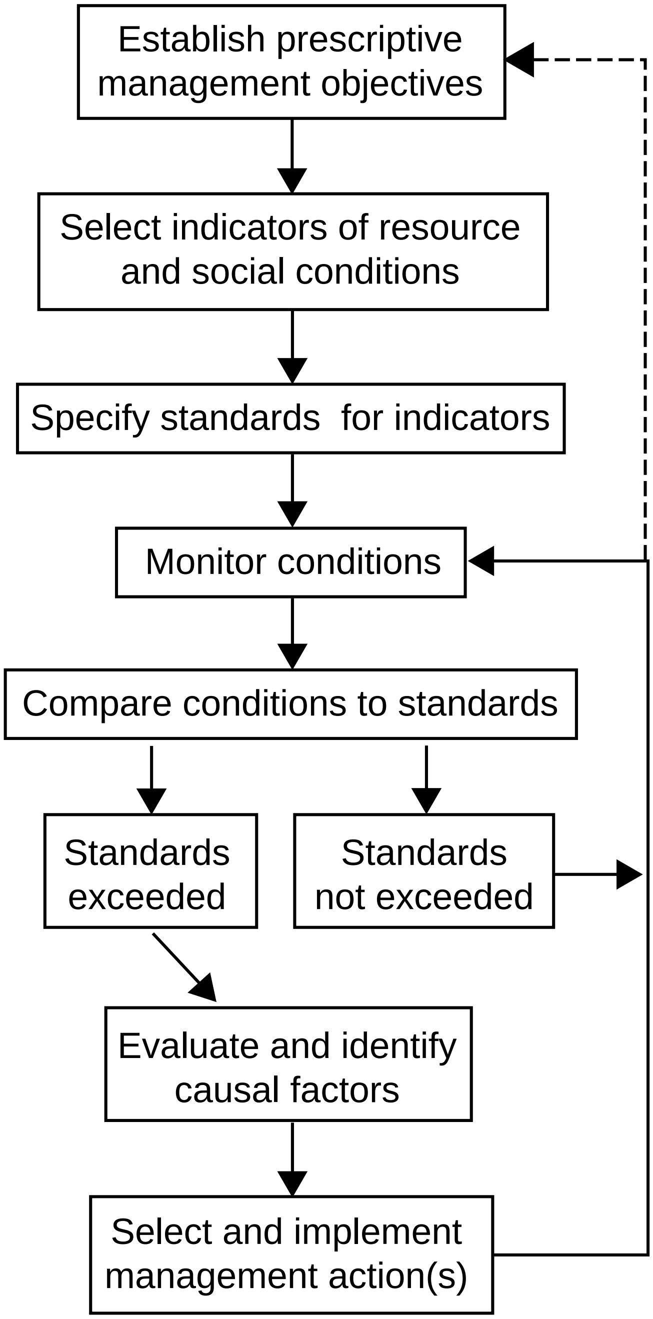

Figure 5—Diagram illustrating contemporary management planning frameworks such as LAC, VIM and VERP.

for the implementation of corrective actions that will avoid severe or irreversible impacts.

Monitoring data may also help gauge the effectiveness of management interventions implemented to correct deteriorating or unacceptable resource conditions. For example, analysis of campsite monitoring data at Delaware Water Gap National Recreation Area revealed the success of several site and visitor management actions implemented following the initial monitoring survey (Marion 1995).

Monitoring data may assist in identifying the underlying causes of impacts and help managers select effective management strategies and actions. For example, campsite monitoring data at Shenandoah National Park were used to develop campsite selection criteria based on vegetation type, topography and aspect (Williams and Marion 1995). Park staff are applying these criteria to rank existing campsites and potential campsite locations to shift camping to more durable locations.

Other uses of monitoring information include the formulation and justification of budget requests and resource or visitor management actions (Marion 1995). For example, monitoring data documenting a decline in trail conditions over time might suggest the need for increased trail maintenance funding. Similarly, data showing an increasing trend in tree damage following educational efforts might justify a ban on axes and saws. Finally, monitoring data may be used to assign limited agency funding or staffing within different wildernesses or regions of a single wilderness.

Knowledge Gaps and Future Directions

Recreation ecology is essential to the professional management of wilderness resources and recreational experiences. Managers frequently turn to scientific knowledge for the information needed to make informed decisions. The inadequate knowledge base of recreation resource impacts has meant that managers must act in the absence of scientific information, taking actions that are increasingly being challenged by the public.

Basic Processes and Factors

Cole and Landres (1996) reviewed various threats to wilderness ecosystems, including criteria for evaluating their significance. They highlighted gaps in knowledge about the pollution of water bodies and alteration of their biota due to the introduction of fish, disruption of natural conditions due to fishing, hunting and the introduction and translocation of game animals, belowground processes, including biotic-biotic interactions, and of nonconsumptive visitor impacts to wildlife. Many of these impacts, particularly at larger spatial and temporal scales, are so poorly understood that effective impact indicators cannot be identified, and monitoring programs cannot be initiated (Cole and Landres 1996).

Long-Term Consequences and Significance of Impact

More longitudinal research and monitoring studies are needed to document and evaluate the long-term consequences of wilderness visitation (Cole and Landres 1996; Hartley 1999). Managers are increasingly adopting containment strategies for limiting visitor impacts, concentrating and reducing the areal extent of traffic. A primary question is whether such locations will be able to sustain such intensive visitation and what ecological consequences this policy will produce. A more thorough examination of the managerial, ecological and social significance of recreation resource impacts is also needed.

Design, Accuracy, and Precision Issues in Impact Assessment and Monitoring

Increasing application of management decision frameworks that employ indicators and standards requires more objective resource monitoring protocols and programs. Few investigations of the accuracy and precision of existing impact assessment and monitoring methodologies have been conducted. Results suggest considerable subjectivity in assessment procedures for some indicators. Additional investigations are needed to characterize and find new ways to reduce measurement error so that monitoring data reflect real changes in resource conditions. Further work on employing the results of precision investigations to define confidence intervals for management decisionmaking is also needed (see Williams and Marion 1995). Working at odds with this issue is the need for efficient and flexible monitoring protocols; otherwise managing agencies cannot adopt or sustain them over time.

Management Effectiveness

Most recreation ecology investigations have focused directly on relationships between use-related and environmental factors and fail to consider management interventions that seek to manipulate these factors. The effectiveness of management actions in avoiding or minimizing visitor impacts represents a significant and largely untapped research topic of considerable importance to managers. Examples include evaluations of improved campsite or trail design and construction, containment and dispersal impact management strategies, visitor management practices such as group size limits and Leave No Trace educational efforts, use of facilities such as fire grates, and campsite and trail maintenance efforts. Very little is known about the relative effectiveness of these and other management strategies and tactics, or the role of supporting actions.

New Locations, Activities, and Technologies

Early investigations of recreation impacts often focused on large and remote wilderness areas in the western U.S. Recently research has expanded to Midwestern and Eastern states, as well as high-use wilderness destinations (Cole and others 1997). More research is needed in high-use areas to assess the magnitude of impacts and evaluate the effectiveness of management actions in more intensively visited locations.

Impacts from off-trail hiking or dispersed activities around campsites have seldom been documented. One example is the potential ecological effects of off-site trampling and wood removal related to campfire wood collection.

As new recreation pursuits and new types of recreation equipment are gaining popularity in wilderness, there will be needs for corresponding research. One example is the use of hiking poles, which have become a common hiking and backpacking aid. Initial observations seem to suggest that poles with long sharp tips could loosen soil aggregates, possibly leading to increased muddiness and erosion by water or wind. However, no research that we are aware of has been conducted to determine potential impacts induced by hiking poles. More empirical research is also needed for examining the impacts caused by expanding or new activities such as climbing, caving and the use of llamas.

The rapid advancement of computer and other technologies offers great potential for recreation ecology investigations, but few benefits have been realized. Promising technologies include global positioning system (GPS), geographic information systems (GIS), image capture technology and the Internet. With a greater accuracy and direct transferability of data to computer systems, GPS has been used for mapping the location of wilderness campsites and trails (Leung and Marion 1995; Monz 1998) and recently experimented on backcountry trails. The use of GIS is expanding, with a growing number of applications from spatial mapping and display of visitor distribution patterns (Wing and Shelby 1999) to spatial planning to predict potential human-wildlife conflict zones (Harris and others 1995). Image capture technology has been applied to simulate different scenarios of campsite impacts (Nassauer 1990). The Internet and World Wide Web offer an unprecedented opportunity to disseminate research results of recreation ecology studies and low-impact recreation practices. Although the applications are currently limited, use of these technologies will soon be common in all aspects of wilderness recreation research, including recreation ecology studies.

Staffing and Funding

Little progress has been made in the previous 15 years to develop and expand permanent recreation ecology research programs. The Aldo Leopold Wilderness Research Institute, established in 1993 by the USDA Forest Service, is the only national research group dedicated to developing the knowledge needed to improve the management of wilderness and other natural areas. Only one scientist at the Institute conducts research on recreation impacts in wilderness. Similarly, only one scientist in the U.S. Department of the Interior focuses on recreation impacts, in spite of that agency's considerable land and recreation management responsibilities - including National Park Service units, U.S. Fish and Wildlife Refuges and Bureau of Land Management areas. Academia and a nonprofit organization, the National Outdoor Leadership School, also each employ one scientist in the recreation ecology field of study, contributing to a national total of four scientists.

Funding is also extremely limited, with the Leopold Institute the only organization having a permanent base of annual research funding. This funding may be used to address system-wide or regional information needs of a basic or applied nature. However, even this support is generally insufficient for studies other than those of the Institute's recreation ecologist. Other funding is derived primarily from national forests and parks and is tied to specific management information needs. The most common needs over the past 15 years have been the development and initial application of visitor impact assessment and monitoring protocols.

Enhanced support for permanent federal land management sponsored centers of recreation ecology research are needed. Increased funding, particularly for basic research focused on the improvement of fundamental recreation ecology knowledge and methodological development, is required to move this field of study to an advanced level of understanding. An increased number of scientists, representing a greater array of disciplines, are also essential to build the critical mass of researchers necessary to substantially advance knowledge. For example, there has never been a recreation ecologist with a career-level focus on visitor impacts to wildlife.

Concluding Remarks

Wilderness managers continue to be confronted by significant visitor impact problems throughout the 624-unit, 104-million-acre National Wilderness Preservation System. Visitor impacts threaten to compromise wilderness management mandates for preserving and sustaining high quality natural environments and recreational experiences. A principal goal for managing wilderness visitation is to avoid impacts that are avoidable and to minimize those that are not. To achieve this goal, wilderness managers must effectively educate and regulate visitors and manage wilderness resources.

While the areal extent of visitor impacts remains small, there is growing recognition and appreciation of their ecological, social and managerial significance. Recreation ecology has begun to document many of the impacts occurring to vegetation, soils, wildlife and water resources. Studies are also beginning to describe the extent and rates of change of these impacts, where they are occurring and their relationships to causal and noncausal factors. However, considerable gaps in our knowledge continue, and existing research staffing and funding severely limit the attainment of further knowledge.

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