REVIEW ARTICLE

*J. For.* 114(3):339–351
http://dx.doi.org/10.5849/jof.15-062

recreation

# A Review and Synthesis of Recreation Ecology Research Supporting Carrying Capacity and Visitor Use Management Decisionmaking

**Jeffrey L. Marion**

Resource and experiential impacts associated with visitation to wilderness and other similar backcountry settings have long been addressed by land managers under the context of "carrying capacity" decisionmaking. Determining a maximum level of allowable use, below which high-quality resource and experiential conditions would be sustained, was an early focus in the 1960s and 1970s. However, decades of recreation ecology research have shown that the severity and areal extent of visitor impact problems are influenced by an interrelated array of use-related, environmental, and managerial factors. This complexity, with similar findings from social science research, prompted scientists and managers to develop more comprehensive carrying capacity frameworks, including a new Visitor Use Management framework. These frameworks rely on a diverse array of management strategies and actions, often termed a "management toolbox," for resolving visitor impact problems. This article reviews the most recent and relevant recreation ecology studies that have been applied in wildland settings to avoid or minimize resource impacts. The key findings and their management implications are highlighted to support the professional management of common trail, recreation site, and wildlife impact problems. These studies illustrate the need to select from a more diverse array of impact management strategies and actions based on an evaluation of problems to identify the most influential factors that can be manipulated.

**Keywords:** recreation ecology, carrying capacity, visitor impact management, management efficacy, wilderness, visitor use management

Visitor impacts to wilderness and similar backcountry "wildland" settings represent an increasing challenge for land managers guided by mandates to achieve and maintain high-quality resource conditions and visitor experiences. As reviewed in the accompanying article (Marion et al. 2016), recreation ecology studies have documented the types and severity of impacts occurring to vegetation, soils, wildlife, and water resources (see also Cole 2004, Monz et al. 2010, Newsome et al. 2013, Hammitt et al. 2015). An understanding of these impacts and their areal extent, rates of change, and relationships to important causal and influential factors is critical to selecting and implementing effective management responses that avoid or minimize recreation-related resource impacts. This article updates Leung and Marion (2000a), providing a state-of-knowledge review of recent recreation ecology studies that inform the development of effective carrying capacity and visitor impact management decisionmaking, including strategies and actions for minimizing resource impacts caused by visitation in wildland settings.

Carrying capacity has long provided the predominant framework for planning and management decisionmaking that addresses the protection of natural resource and social conditions (Manning 2011). Over time, managers have shifted from a narrow focus on numeric carrying capacity to a broader decisionmaking process that incorporates a more comprehensive array of management strategies and actions (Graefe et al. 2011). Most recently, six US federal agencies (the Bureau of Land Management, the Forest Service, the National Oceanic and Atmospheric administration, the National Park Service, the US Army Corps of Engineers, and the Fish and Wildlife Service) formed an Interagency Visitor Use Management Council (IVUMC) to "increase awareness of and commitment to proactive, professional, and science-based visitor use management on federally-managed lands and waters."[1]

Received May 5, 2015; accepted January 27, 2016; published online March 17, 2016.

**Affiliations:** *Jeffrey L. Marion (jmarion@vt.edu), US Geological Survey, Virginia Tech Field Station, Blacksburg, VA.*

**Acknowledgments:** *I thank Jeremy Wimpey, Applied Trails Research, and the anonymous peer reviewers for their constructive comments.*

They define "Visitor Use Management" as the

> proactive and adaptive process for managing characteristics of visitor use and the natural and managerial setting using a variety of strategies and tools to achieve and maintain desired resource conditions and visitor experiences.

They emphasize that managing visitor access and use for recreational benefits and resource protection is inherently complex, requiring consideration of natural and social science studies, management experience, and professional judgment.

This article briefly describes the new IVUMC Visitor Use Management (VUM) planning and decisionmaking process and provides support for this and carrying capacity decisionmaking through a state-of-knowledge review and synthesis of the recreation ecology literature organized around five core visitor impact management strategies. This review informs development of a comprehensive "management toolbox" of options that extend beyond use reduction to include the redistribution of visitor use, improved sustainability of recreation infrastructures, persuasive communication and regulations to promote low impact behaviors, and restoration practices to accelerate the recovery of resource conditions judged to exceed acceptable limits. Recreation ecology studies that have developed resource condition assessment and monitoring methods are also briefly reviewed.

## From Carrying Capacity to Visitor Use Management

Wildland managers operate under laws and administrative policies, directing them to achieve a "balance" between competing "recreation provision" and "resource protection" objectives. For example, 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." The traditional body of knowledge developed by managers and scientists to address the negative impacts of visitation to resource and social conditions was termed "carrying capacity." Whereas the early management activity and literature focused on defining a numeric limit on visitor numbers below which resource and social conditions would be protected, several decades of management and research experience have demonstrated that amount of use is strongly correlated with the magnitude of resource impact only at low levels of use (see Marion et al. 2016). Thus, limiting use is often an ineffective means for achieving resource protection objectives on moderate- to high-use trails and recreation sites, prompting the need to consider a diverse array of alternative considerations and actions (Wagar 1964, Leung and Marion 2000a, Manning 2007, 2011). This is widely accepted in the context of minimizing resource impacts, although court challenges based on dated laws specifying the role that numerical limits should play in carrying capacity planning continue to focus management attention on visitor numbers (Capacity Work Group 2010, Graefe et al. 2011, Whittaker et al. 2011).

To illustrate the influence of other factors, consider a typical natural-surfaced trail that receives the same amount of use over its length yet has sections that are variously narrow or wide, dry or muddy, and smooth or eroded. Factors such as vegetation and soil type and the sustainability of the trail's design, construction, and maintenance vary along the trail and their substantial influence is readily apparent to both visitors and trail professionals (Marion and Leung 2004). Because of the general asymptotic use/impact relationship and strong influence of other factors, reducing use on a heavily used trail by 20% is often unlikely to result in any meaningful improvement in trail conditions. The recreation ecology studies reviewed in this article reveal that other factors are generally more effective for minimizing resource impacts, including sustainable siting and designs for recreation trails, sites, and facilities relative to topography and soil/vegetation type, actions that spatially concentrate activity to a limited "footprint" of disturbance, and regulations and persuasive communication that promote low-impact behaviors (Leung and Marion 2000a, Marion 2014, Hammitt et al. 2015). Similar findings have been identified for social impacts like crowding and conflict, such as the significant influence of visitor motives, use type, user behavior, and the location or timing of encounters (Manning 2007, 2011).

An array of planning and decisionmaking frameworks have been developed to provide guidance for this expanded complexity (Manning 2011). These frameworks are more broadly focused on managing visitor use to protect resources and provide high-quality experiences, with numeric carrying capacity determinations included as an option when needed or required by law. The most widely applied frameworks are the US Department of Agriculture Forest Service Limits of Acceptable Change (LAC) and the National Park Service Visitor Experience and Resource Protection (VERP) frameworks (Stankey et al. 1985, National Park Service 1997). Common attributes include prescriptive management objectives that define desired resource and social conditions, selection of indicators and standards of acceptable change, monitoring to compare current conditions with standards, and implementation and evaluation of corrective management actions. These frameworks have been incorporated into many federal protected area planning documents, although staffing and funding levels frequently challenge and even prevent managers from sustaining their effective use (Farrell and Marion 2002, Manning 2007). In response, Farrell and Marion (2002) pro-

### Management and Policy Implications

Wildland managers struggle to balance their resource protection and recreation provision objectives. Over the course of six decades, the recreation carrying capacity concept has been repeatedly applied and revised as a management tool, evolving from a simplistic focus on fixed visitation limits to comprehensive decisionmaking frameworks focused on sustaining high-quality recreational opportunities. Recreation ecology studies investigating relationships between amount of visitor use and the magnitude of resource impacts consistently find that use and impact are strongly related only at initial and low levels of visitation, with weak correlations at higher use levels. However, unacceptable resource impacts often occur on well-established and heavily used trails and recreation sites: reducing use to improve their condition is generally an ineffective practice. An increasing number of recreation ecology studies describe the efficacy of alternative management interventions, including the siting, design, construction, and maintenance of more sustainable trails and recreation sites, the spatial and temporal redistribution of visitor use, and persuasive communication or regulations that encourage visitors to apply low-impact practices.

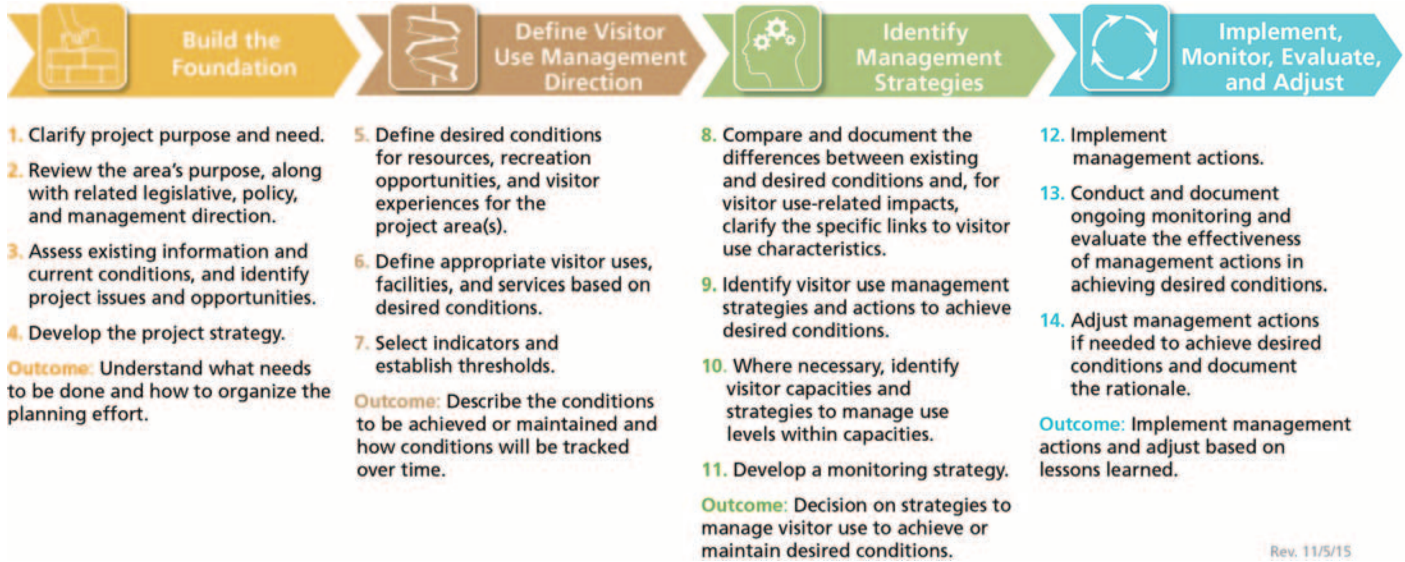


**Figure 1. The Interagency Visitor Use Management Council has developed a new Visitor Use Management framework for federal land management agencies that includes four core elements and 14 steps.**

posed the Protected Areas Visitor Impact Management (PAVIM) framework, which increases efficiency through greater reliance on expert panels of managers, scientists, and knowledgeable stakeholders.

More recently, the IVUMC has developed a new VUM planning and decision-making framework to provide consistent guidance for federal land management agencies (Figure 1).[1] This framework is similar to and consistent with LAC and VERP but incorporates lessons learned from agency experience to address past planning and legal challenges (Graefe et al. 2011, Whittaker et al. 2011). For example, it contains a "sliding scale of analysis" in each step to match analytical investments with the level of complexity and risk associated with the issues being addressed. VUM incorporates additional guidance for carrying capacity decisionmaking when needed, but its primary focus is on visitor use management topics, including park development, transportation planning, and commercial uses. Implementation of VUM has already begun in several federal agencies.

Recreation ecology knowledge provides essential information for a number of key VUM framework elements and steps (Figure 1). For example, methods to quantitatively describe and monitor different types of recreation-related resource impacts over time are a core component of recreation ecology studies (Hill and Pickering 2009, Leung et al. 2011, Marion et al. 2011a, Cole 2013a, Cole and Parsons 2013). These types of studies are applicable to VUM steps 3, 5, 7, 8, 11, and 13. Many recreation ecology studies use relational analyses to model resource degradation, revealing insights that inform the selection of effective management interventions (Hadwen et al. 2008, Olive and Marion 2009, Pickering 2010, Wimpey and Marion 2010, Monz et al. 2013). These types of studies are critical to VUM steps 8, 9, 10, 13, and 14. A few studies have even evaluated the efficacy of implemented management actions (Reid and Marion 2004, 2005, Marion and Reid 2007, Marion et al. 2008).

## Monitoring Visitor Impacts

Visitor impact monitoring protocols are often developed by scientists for use by managers to provide accurate and precise data on physical attributes (e.g., trail width or campsite size), vegetation cover, tree damage, and soil exposure, muddiness, or loss (Marion 1991, Cole 2006). More thorough reviews of the visitor impact monitoring literature, assessment methods and manuals, and examples of monitoring data indicators can be found in publications for formal trails (Dixon et al. 2004, Hawes et al. 2006, Hill and Pickering 2009, Marion and Carr 2009, Marion and Leung 2011, Marion et al. 2006, 2011a), informal (visitor-created) trails (Leung and Louie 2008, Leung et al. 2011, Marion and Wimpey 2011, Marion et al. 2011b), and recreation sites and campsites (Marion and Carr 2007, 2009, Cole 2013a, Cole and Parsons 2013, Newsome et al. 2013).

## Managing Visitor Impacts

A diverse array of visitor use management strategies and actions has been proposed to address visitor impact management problems (Anderson et al. 1998, Hendee and Dawson 2002, Hammitt et al. 2015). Cole et al. (1987) proposed eight categories of strategies and tactics with management guidance to address common wilderness management problems, reorganized into five core strategies in Table 1. Management interventions seek to avoid or minimize impacts by manipulating either use-related factors (e.g., amount or type of use and user behaviors) or environmental factors (e.g., environmental resistance and resilience related to vegetation or soil attributes, topography, and others) (Pickering 2010, Hammitt et al. 2015).

The balance of this article reviews the most relevant and recent recreation ecology literature that informs the selection of effective visitor impact management strategies and actions presented under the five core strategies outlined in Table 1. These can be broadly grouped into two categories: *visitor management strategies* (Table 1, numbers 1, 2, and 4) that reduce use, concentrate or disperse recreation activity on durable substrates, or modify visitor behavior to minimize resource impact and *site management strategies* (Table 1, numbers 3 and 5) that develop sustainable impact-resistant trails and recreation sites or close and hasten recovery on unnecessary or less sustainable trails and sites.

**Table 1. Core management strategies and actions for avoiding or minimizing resource and social impacts in wildland settings.**

| Core strategies | Management actions |
|---|---|
| 1. Manage use levels | Redistribute, discourage, or limit use (e.g., set access point or travel zone quotas).<br>Redistribute or reduce use during times of peak use, in high use locations, or when impact potential is high. |
| 2. Modify the location of use | Concentrate use on sustainable expansion-resistant trails and campsites to limit the aggregate area of impact.<br>Disperse use on durable substrates at levels that prevent formation of trails and campsites.<br>Encourage or require visitors to camp out of sight or a minimum distance from trails and campsites.<br>Restrict certain types of use to specific locations (e.g., restrict horses to trails and campsites designed for their use). |
| 3. Increase resource resistance | Construct, reconstruct, or maintain impact-resistant trails and campsites (e.g., construct side-hill trails and campsites, install anchored campfire rings). |
| 4. Modify visitor behavior | Persuasive communication, interpretation, or education: encourage or require Leave No Trace practices when traveling and camping.<br>Regulation and enforcement: prohibit or require certain practices and equipment when traveling and camping (e.g., feeding wildlife, safe food/trash storage, woods tools). |
| 5. Close and rehabilitate the resource | Close and rehabilitate unnecessary or less sustainable trail segments and campsites. |

Adapted from Cole et al. (1987) and Marion (2003).

***Indirect versus Direct Actions.*** The following examines some "traditional" guidance regarding indirect versus direct management actions. Some early scientists suggested what has become a commonly applied wilderness management principle: that indirect management actions should be applied first, followed by more direct actions if needed. Another principle is that use limitation should be a direct action of last resort, applied only when other actions have been shown to be ineffective (Hendee et al. 1990). Such guidance may seem appropriate when one considers the potential negative impacts of direct actions on visitor access, freedom, and experiential quality. However, Cole (1995d) suggests that such dogma can be inappropriate when routinely applied, in some instances preserving visitor freedoms at the expense of environmental degradation. For example, Cole (1995d) and McAvoy and Dustin (1983) argue that coercion can be effective and necessary to halt the types of degradation that occur quickly yet require decades to recover from.

Consider research findings from the Boundary Waters Canoe Area Wilderness (BWCAW) and the Great Smoky Mountains National Park (GSMNP) demonstrating substantial levels of tree damage and felling despite the long-term operation of comprehensive low-impact educational programs in both areas. A study of campsite impacts at GSMNP found 2,377 damaged trees and 3,366 cut tree stumps (Marion and Leung 1997), whereas current research on 81 BWCAW campsites tallied an average of 11 damaged trees and 18 tree stumps per site, equating to 22,000 damaged trees and 36,000 felled trees for the entire area. These findings suggest that the widely communicated Leave No Trace firewood gathering practices have failed to effectively limit tree damage and felling and that a direct regulation prohibiting woods tools (axes, hatchets, saws) is justified and could be a more effective action. Consider also that tree damage and felling are core reasons why protected area managers are increasingly prohibiting campfires: a 1991 survey of National Park Service units with substantial backcountry and wilderness found that 43% prohibited campfires (Marion et al. 1993). Thus, limiting one freedom (using woods tools) could preserve another freedom (having a campfire). Campers can have campfires without these implements, and leaving them at home avoids the felling of trees or the likelihood of significant damage.

Selecting and implementing an effective management action to avoid or minimize visitor impacts requires the following: knowledge and consideration of the underlying causes and influential factors affecting the impacts; and careful consideration of a range of alternative actions to evaluate their potential effectiveness and impact on visitor experiences. The following sections review recent research and case studies that have effectively applied recreation ecology knowledge to reduce visitor impacts under each of the five core management strategies included in Table 1. As will be revealed, effective management actions target the most influential factors, account for causal and contextual factors, and often employ more than one strategy or action.

## The Visitor Impact Management Toolbox

### Manage Use Levels

As described in the accompanying article (Marion et al. 2016), most forest types have ground vegetation that is neither resistant nor resilient to trampling; even open meadow vegetation with resistant grasses and sedges cannot sustain more than 1 or 2 weeks of camping. As depicted in Figure 2, above a relatively low threshold of trampling pressure, impacts occur rapidly as plants and organic litter are trampled and lost. This is followed by the exposure and loss of organic

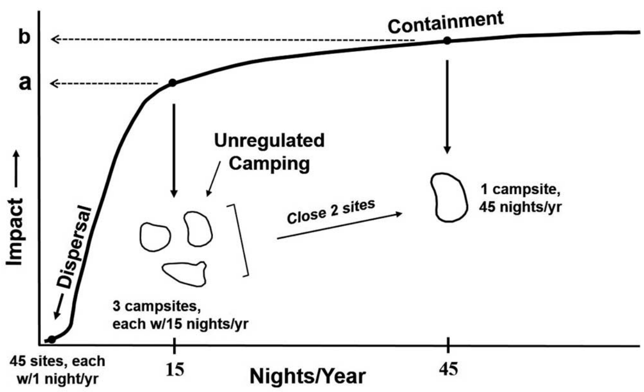


**Figure 2. A generalized model of the use-impact relationship for trampling on vegetation and soil illustrating when use-reduction is and is not effective and the empirical basis for effective dispersal and containment strategies.**


**Figure 3. Successful dispersed camping is challenging to implement and requires visitors to learn and apply Leave No Trace "pristine-site" camping practices.**

soil and compaction of underlying mineral soil. Once the majority of vegetation and litter cover have been lost, soil compaction occurs quickly, and further increases in visitation result in diminishing amounts of vegetation and soil impact. Trail, campsite, and experimental trampling studies have consistently documented this nonlinear asymptotic use-impact relationship between the amount of recreational trampling and most types of vegetation and soil impacts (Cole 1995a, b, Monz et al. 2010, Hammitt et al. 2015). This asymptotic use-impact relationship has also been consistently documented in other countries with diverse vegetation and soil types (Littlemore and Barker 2001, Whinam and Chilcott 2003, Roovers et al. 2004, Hill and Pickering 2009, Pickering et al. 2010, Newsome et al. 2013, Barros and Pickering 2015).

The implication of this use-impact relationship is that reducing use on well-established moderate- to high-use trails and recreation sites is unlikely to appreciably diminish vegetation and soil impacts; it is an ineffective strategy unless substantial reductions occur (Figure 2). In contrast, limiting use within the low-use zone, where impacts occur rapidly, can lead to substantial reductions in vegetation and soil impact. However, this zone occurs at relatively low levels of traffic, generally between 3 and 15 nights of camping per year or 50 to 250 passes per year along a trail (Cole 1995a, 1995b, 1995c).

There are a few important caveats to these general findings. Limitations on the number of overnight groups during times of peak use can effectively reduce the aggregate area of camping disturbance by limiting the number of campsites needed. Campsites are often created by visitors during peak use periods when campsite occupancy rates are high. Subsequent use of new campsites, even a few nights/year, is sufficient to prevent their recovery (Scherrer and Pickering 2006, Cole 2013b). The timing and location of use also influence the amount of impact that the same number of visitors can have. For example, visitors have substantially greater impact on wet soils than on dry soils or on growing plants than the senesced fall/winter remnants. Visitors can also travel or camp on durable nonvegetated substrates such as gravel, rock, and snow or artificial substrates such as wood and rockwork on trails that support substantial traffic with very limited impact. Finally, Monz et al. (2013) note the possibility of alternative use-impact response curves for other types of impact, including wildlife responses and aquatic systems that may have differing management implications.

## Modify the Location of Use

What happens when recreational activities are unmanaged in protected natural areas? Studies reveal that unmanaged visitation frequently results in considerably greater recreational impact. For example, informal (visitor-created) trails have design attributes that make them less sustainable than professionally designed formal trails (Wimpey and Marion 2011). Similarly, visitors frequently create campsites in large flat areas

**Figure 4. The author assessing camping impacts to vegetation on campsites in the Boundary Waters Canoe Area Wilderness. Note that recreational traffic has eliminated most herbaceous plants and favored grasses and sedges, which are better able to resist or recover from trampling damage. (Photo by Holly Eagleston.)**

with fragile herbaceous vegetation along the banks of streams. Site expansion and proliferation are common in such areas, leading to excessive resource impacts and problems with visitor crowding and conflict (Cole 1993, Leung and Marion 2000b, Reid and Marion 2004).

A manager's ability to manipulate the location of visitor activity is one of the most powerful strategies in the visitor impact management toolbox (Leung and Marion 1999). Managers can attempt to contain use on a sustainable infrastructure of trails, campsites, and recreation sites, focus intensive traffic on the most durable artificial or natural substrates, separate visitors to promote solitude or prevent conflicts, or disperse use to levels that avoid lasting impact (Hendee and Dawson 2002, Manning and Anderson 2012). Let us begin by reexamining additional implications from the use-impact curve in Figure 2. Consider a hypothetical example of unregulated camping with three campsites, each receiving 15 nights/year and cumulative resource impact equivalent to three times the "a" amount (Figure 2). The most effective dispersal strategy would eliminate all persistent impacts by shifting use from the 3 sites to 45 forested sites or to 15–20 meadow sites (due to their greater trampling resistance) (Cole 1992, 1995c).

The core objective of a dispersal strategy is to reduce traffic to levels that prevent formation of resource impacts lasting more than a year (Cole and Monz 2003, 2004); this level of dispersal would also effectively resolve problems with visitor crowding and conflict. Successful dispersed camping requires visitors to apply Leave No Trace "pristine site" camping practices (Figure 3), which are facilitated by camping in areas with little ground vegetation or on resistant and resilient dry grasses (Figure 4) or using hammocks (Marion 2014). Unfortunately, few managers have had success with a dispersal strategy for the following reasons: limitations on the number of available camping areas with resistant vegetation and/or durable substrates; an inability to effectively inform visitors of the strategy and associated "pristine site" camping practices; and failure by visitors to adhere to the dispersal strategy and practices. This strategy has, however, been effectively applied in some remote low-use protected areas, particularly in Alaska (Marion and Wimpey 2011).

For protected areas with moderate to high visitation, a containment and concentration strategy is preferred and has been effectively applied (Leung and Marion 1999). The core objective of a concentration strategy is to contain camping impact to the smallest number of sites needed and to spatially concentrate camping activity on each site to minimize the total or aggregate area of camping disturbance (Cole 1992, Leung and Marion 2004, Hammitt et al. 2015). As shown in Figure 2, managers would close two campsites and shift use to the third, preferably a site with durable substrates and limited expansion potential. Because of the curvilinear use-impact relationship, impact on this third site would increase only marginally, from "a" to "b," and aggregate impact would decline substantially, from three sites with an "a" level of impact to one site with a "b" level of impact (Figure 2). Effective application of this strategy requires education and/or regulations directing visitors to camp only on designated or well-established campsites and to spatially concentrate their activities within core areas. Problems with crowding and conflict can be resolved by physically separating campsites from each other and from trails (Manning and Anderson 2012).

A containment strategy minimizes aggregate impact by restricting camping to a small number of designated expansion-resistant campsites, with the greatest effect achieved through a reservation system that links groups to specific campsites to achieve high occupancy rates. Unfortunately, reservation systems force visitors to adopt a rigid itinerary that may be difficult to keep and which substantially limits freedom and spontaneity (Stewart 1989). Less rigid containment options require or ask visitors to use any available designated or "well-established" campsite, which allows managers to close and restore unnecessary and/or less sustainable sites (Cole and Benedict 1983, Reid and Marion 2004). To avoid the "musical chairs" dilemma of too many groups for available site numbers managers must match the number and distribution of campsites with surveys of camping demand or manipulate entry point or travel zone quotas to match demand with supply. Although reservation systems can achieve exceptionally high campsite occupancy rates, designated or established site camping without reservations can still reduce aggregate camping impact by targeting occupancy rates in the 50–80% range. These less rigid camping management options trade off the benefits of increased visitor freedom against the resource protection "cost" of retaining a larger inventory of campsites with greater aggregate impact. Visitors may need to share sites or employ pristine site camping during peak use periods if all available sites are used.

Another important and relevant recreation ecology research finding is that resource impacts occur rapidly on new trails and campsites but that recovery rates are substantially slower (Leung and Marion 2000, Cole 2013b, Hammitt et al. 2015). At Delaware Water Gap National Recreation Area, experimental trampling and longitudinal campsite research found stable conditions with little annual change on well-established campsites over a 5-year period, but substantial resource changes on new campsites, primarily occurring during their first year of use (Marion and Cole 1996). By year 3, resource conditions on the new campsites resembled those on well-established campsites. In contrast, campsites closed to use recovered at much slower annual rates and after 6 years the floristic composition of vegetation still differed from that of adjacent undisturbed areas, despite more favorable recovery conditions and rates than reported in most other recovery studies.

The principal implications of these findings are the following: that aggregate camping impact is optimally minimized by containing camping activity to a small number of well-used expansion-resistant campsites and that temporary closure and rest-rotation schemes are ineffective because impact rates far exceed recovery rates. Several recreation ecology studies support and illustrate these findings and implications with empirical data. The managers at Delaware Water Gap National Recreation Area closed 39 of the least sustainable river campsites, shifting their visitation to the most resistant 77 remaining sites. To minimize campsite size, they sought to concentrate camping activities by installing anchored fire rings to attract use to their vicinity (Marion 1995). This containment strategy was highly effective, reducing the total area of camping disturbance from 303,229 to 150,915 $ft^2$, a 50% reduction over 5 years. Despite higher occupancy rates and use, median campsite size declined slightly, from 1,367 to 1,302 $ft^2$, attributed to the selection of expansion-resistant sites and increased spatial concentration of activity around the fire rings.

At Shenandoah National Park, managers converted an ineffective dispersed camping strategy to a containment strategy by closing and rehabilitating large numbers of wilderness campsites (Reid and Marion 2004). A core factor in selecting campsites to remain open was their expansion potential related to topography, rockiness, and dense woody vegetation. Within three areas selected for study, 73 campsites with an aggregate disturbed area of 22,842 $ft^2$ were reduced to 37 campsites and a disturbed area of 11,292 $ft^2$. Campsite numbers were reduced by 49%, aggregate area of disturbance by 50%, and mean size by 3%, despite an estimated 53% increase in campsite visitation (from 19 to 29 nights/year). Campsite occupancy rates increased from 16 to 50%. These results substantiate Cole's (1992) theoretical campsite impact model.

In an Arkansas wilderness Cole and Ferguson (2009) report managers used trail relocation, education, campsite closures, and site restoration work to reduce campsite numbers by 40%, from 91 to 54 sites over 13 years; 21 new campsites were created but 58 sites recovered such that they were no longer recognizable. Cole and Fitchler (1983) present results from campsite studies in three western wilderness areas, concluding that impacts are best minimized by limiting use to a small number of sustainable and professionally managed sites, with dispersed pristine site camping reserved for remote low-use areas. Finally, managers may find that combined strategies can offer substantial flexibility in balancing resource protection and recreation provision objectives. For example, managers might prohibit camping in sensitive cultural and natural resource areas, employ designated site camping in moderate use areas, and enact reserved site camping at the most popular destinations.

These same relationships and implications apply for limiting trail impacts. Land managers have long used a containment strategy by focusing all types of traffic onto sustainably designed and "hardened" trails. However, formal trails can rarely access all of the locations sought by visitors (e.g., climbing sites, fishing/swimming holes, and vistas) so some off-trail travel is inevitable. Unfortunately, unmanaged visitation tends to create large networks of informal trails with duplicative routings and alignments that are less sustainable than professionally designed trails (Wimpey and Marion 2011, Barros et al. 2013). This maximizes impact compared with that of a dispersal strategy that avoids informal trail formation or a strict containment strategy that focuses travel on new formal trails or on a selection of resistant informal trails. See Cole (1992) for additional insights and management implications based on modeling relationships between resource impact and amount of use, vegetation fragility, and degree of activity concentration.

Management experience at Acadia National Park illustrates the application of recreation ecology findings to reduce informal trail impacts. Jacobi (2004) reported 1996 survey data documenting a 2.96-mile network of informal trails on Little Moose Island, a small undeveloped "wilderness" island accessible by foot only during low tide. After consultations with trail and recreation ecology specialists, park staff implemented an action plan in 2001 that selected 1.09 miles of resistant informal trails to retain while closing the remainder through light brushing and temporary signage. A Leave No Trace educational sign asked visitors to stay on the well-established trails or exposed rock surfaces when exploring the island. Minimal vegetation trimming and natural-appearing tread work was conducted on the retained informal trails, but they were not maintained to formal trail standards. Monitoring evaluations in 2003 revealed no major changes in vegetation cover for the selected trails and substantial recovery underway on the closed trails.

### Increase Resource Resistance

The recreation ecology literature has numerous studies documenting the wide range in resistance and resilience of vegetation and soil types or topography to traffic (see the accompanying article, Marion et al. 2016). This knowledge has been widely applied by managers to shift recreational activities from fragile to resistant environmental settings and facilities as described above or to increase the resistance of existing facilities. For example, when designing sustainable trails, managers can increase their impact resistance by keeping grades under 10%, by employing side-hill alignments (angled <60° from the contour line), and by favoring substrates high in rock or gravel (Marion and Leung 2004, Olive and Marion 2009). To limit camping impact, managers can select sites or promote camping in dry grassy meadows, which resist or quickly recover from trampling damage. Campsite proliferation and expansion can be curtailed by designating small campsites within sloping terrain.

Managers seeking to reduce resource impacts can also apply more sustainable construction and maintenance actions to increase the ability of trails and recreation sites to resist impact. A core objective is to limit site size and aggregate the area of impact. For existing sites, managers have installed facilities that attract and spatially concentrate activities, such as anchored fire grates in the BWCAW or the Delaware Water Gap National Recreation Area. If rock campfire rings are used, managers can deeply embed a few long rocks to identify and make permanent an "official" fire site (Reid and Marion 2005). A camping post, campsite sign, or paint blaze can signify the exact location of a campsite in areas that prohibit campfires. Reworking substrates to provide a few ideal

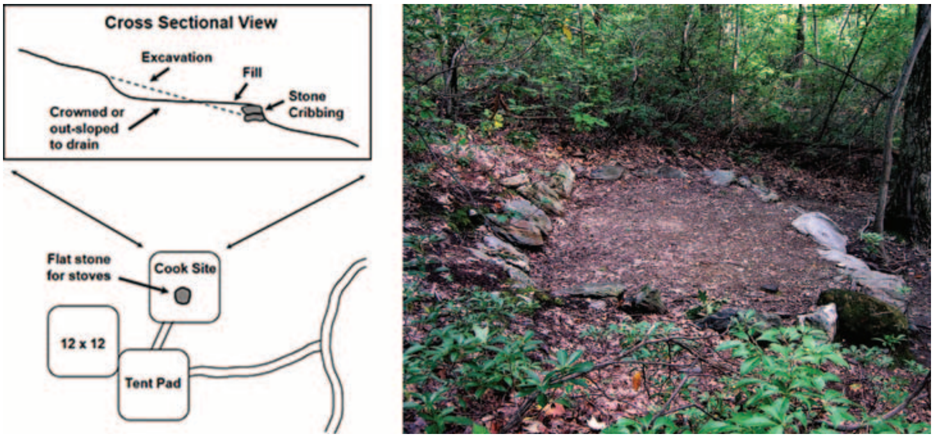


**Figure 5. Left. Side-hill campsite with two tent pads and a cook site. Right. Side-hill campsite on the Appalachian Trail.**

tenting spots within the core campsite area, paired with minimal digging in adjacent peripheral areas to ice-berg rocks or create shallow pits and mounds, can shrink campsite sizes (Marion and Sober 1987, Manning and Anderson 2012).

At Isle Royale National Park, managers constructed "side-hill" campsites by cut-and-fill digging, often enlarging smaller flat spots (Figure 5) (Marion and Farrell 2002). This practice has been widely implemented along the Appalachian Trail (AT) to create more than 600 side-hill campsites in the last 12 years (Marion 2003). The efficacy of this practice was evaluated at Annapolis Rocks in Maryland, selected by the Appalachian Trail Conservancy as one of the two "most impacted AT camping areas" (Manning and Anderson 2012). In 2003, AT club and trail crew staff shifted overnight camping from 19 visitor-created campsites in flat terrain (43,100 ft$^2$ aggregate area of disturbance) to 14 constructed side-hill campsites in sloping terrain (5,759 ft$^2$ postconstruction area of disturbance) (Daniels and Marion 2006b). After 10 years of use, the aggregate area of disturbance on the new side-hill campsites increased to 8,574 ft$^2$, still an 80% reduction from the initial condition (J.L. Marion, US Geological Survey, unpub. data, Jan. 15, 2016). The majority of site expansion occurred on three group use campsites, two of which were located in flatter terrain (grade of <15%; 20–25% is ideal). In addition, site caretakers reported that many large groups do not split up to camp on separate sites as requested.

Trail construction and maintenance activities can increase trail resistance by adding stonework, gravel, borders, or boardwalks (Wimpey and Marion 2010); research by Hill and Pickering (2006) found differences in trailside vegetation cover and composition related to several of these factors. Trail professionals can design, construct, and maintain trails with adequate numbers of tread grade reversals and drainage features (e.g., water crossings, water bars, drainage dips, ditching, and out-sloped treads) (International Mountain Bicycling Association 2004, 2007, Hesselbarth et al. 2007).

Other options developed and applied in frontcountry and backcountry settings require review and evaluation before use in designated wilderness. Geotextile fabrics and cellular confinement products such as geogrids and geocells have been effective in increasing the resistance and load-bearing capacity of wet tread substrates; other effective products include drainage mats (Polynet) and turf reinforcement mats (Pyramat) (Monlux and Vachowski 2000, Meyer 2002, Marion and Leung 2004).[2] A number of chemical binders and natural soil stabilization products have also been developed that increase the adhesion of substrates, improving moisture resistance and bearing and shear strength (Bergmann 1995, Meyer 2002). In general, site management actions should remain "substantially unnoticeable" to visitors—they should be visually and ecologically less obtrusive to natural conditions than the visitor impacts that prompted their consideration (Marion and Sober 1987).

## Modify Visitor Behavior

Many visitor impacts are directly related to human behavior: uninformed, unskilled, or careless behaviors performed by visitors who truly cherish the places they visit (Hendee and Dawson 2002, Manning 2003). When managers reach into their toolbox for options to address recreation-related impacts, persuasive communication focused on low-impact outdoor practices and ethics is often a preferred and effective choice (Newman et al. 2003, Marion and Reid 2007, Lawhon et al. 2013). Hendee and Dawson (2002) note that visitors are highly receptive to interpretive and communication programs, which can improve the quality of visitor experiences by building a deeper appreciation for protected areas, including appropriate low-impact behaviors, experiences, and values (see also Powell and Ham 2008, Ham et al. 2009).

With its 1970s origin in wilderness, the US Leave No Trace program has grown in scope to encompass a diverse array of wilderness, backcountry, frontcountry, and even urban low-impact practices (Marion and Reid 2001, Brame and Cole 2011, Marion 2014). The use of persuasive communication is an "indirect" option focused on expanding visitor awareness of the potential for negative cultural, natural, and experiential impacts and encouraging visitors to learn and apply low-impact outdoor skills and ethics (Hendee and Dawson 2002). Modification of behavior through regulations and their enforcement is an alternative "direct" management option for changing high-impact visitor behaviors. Recreation ecologists have increasingly collaborated with social scientists on applied studies to evaluate the efficacy of alternative communication options for improving adoption of low-impact behaviors. Several of these collaborative studies are reviewed here, although a much larger body of literature exists (see Ham et al. 2009, Kim et al. 2011).

Local, state, and federal land managers, nonprofit organizations, and commercial businesses have widely adopted the national Leave No Trace program to convey a consistent set of low-impact practices to outdoor visitors. The Leave No Trace Center for Outdoor Ethics,[3] with many partners and supporters, has strived to develop effective science-based low-impact practices (Cole 1989, Marion 2014). In addition, numerous recent studies have investigated the theory and mechanisms necessary for educational interventions to cause behavior change (Marion and Reid 2007, Heimlich and Ardoin 2008, Lawhon et al. 2013, Vagias et al. 2014) and to evaluate the efficacy of persuasive communication interventions (Widner and Roggenbuck 2000, Daniels and Marion 2006a, Winter 2006, Park et al. 2008, Bromley et al. 2013). Agency communication programs employ an array of media to convey messaging, including printed material (signs, pamphlets, and books), verbal communication (permitting, interpretive talks, and staff encounters), multimedia and websites, and online or in-person courses (Marion and Reid 2007).

A core question remains: How effective are these programs in encouraging the adoption of low-impact practices? An information-processing model developed by McGuire (1985) describes the necessary steps by which visitors receive, process, comprehend, accept (yield), retain, and act on a persuasive message. Efficacy studies have most frequently used visitor surveys, which can evaluate knowledge gain or ask visitors to report on their recent use of recommended low-impact practices. For example, Cole et al. (1997) assessed the first three steps of McGuire's model, finding that visitors who viewed a wilderness trailhead bulletin board correctly answered 41% of the questions on a low-impact knowledge quiz, compared to 16% for a control group. An Acadia National Park study investigating communication and site management actions designed to discourage off-trail hiking found that based on self-reported behavior, a trailhead sign combined with small symbolic "no-hiking" prompter signs placed at intersections with well-used informal (visitor-created) trails reduced off-trail hiking from 68% in the control to 17% (Park et al. 2008). In a study of visitors to eight wilderness areas, Christensen and Cole (2000) analyzed reported behavior related to persuasive messaging asking visitors to camp away from water. Despite visitors' preferences to camp near water, they found that more than 80% were willing to be persuaded to camp away from water; resource protection arguments were more compelling than social reasons.

Visitors may not be accurate in reporting behaviors after the fact. Greater validity in determining efficacy can be achieved using observers or cameras to evaluate visitor behavior. Winter (2006) used video recordings to evaluate the effectiveness of four alternative wordings for a message designed to discourage off-trail hiking in Sequoia and Kings Canyon National Park. An injunctive-proscriptive wording ("Please don't go off the established paths and trails, to protect the Sequoias and natural vegetation in this park") reduced off-trail hiking from 31% in the control to 5.1%.

A study by Hockett et al. (2010) used concealed observers to evaluate persuasive communication and site management treatments to reduce off-trail hiking and protect rare plants in C&O Canal National Historical Park. Educational trailhead signs and symbolic prompter signs at all intersections with informal trails reduced off-trail hiking from 26 to 6.5%. At Zion National Park, a persuasive sign and personally communicated messages designed to deter visitors from feeding wildlife significantly reduced the percentage of groups that intentionally attracted chipmunks from 24% in the control to 3% for both treatments (Marion et al. 2008). Groups who unintentionally dropped food declined from 41 to 10% when signs were present and to 5% when personal communication was used.

Although persuasive messaging can be effective, some managers believe that direct regulations are more effective (McAvoy and Dustin 1983, Cole 1995d). This may not be true, definitive research needs to be conducted in wildland settings. For example, Reid and Marion (2005) evaluated management actions to address campfire impacts in several parks and wilderness areas, finding within three national parks where backcountry and wilderness campfires were prohibited that nearly half the campsites (48%, 280 of 582 sites) still had campfire sites. Further, they found 511 damaged trees on campsites in these parks, ranging from 28 to 78% of all campsite trees, indicating that regulations prohibiting campfires are also ineffective in substantially reducing tree damage (bans had been in effect for 15–20 years).

Federal law prohibits feeding wildlife in all national parks and wildlife refuges (36 C.F.R. § 2.2), yet both intentional and unintentional wildlife feeding are common problems in national parks. For example, at Grand Canyon National Park managers were forced to kill 22 deer that had become aggressive and dangerous due to feeding by visitors, common in frontcountry and wildland locations (Leslie 1995). Autopsies conducted on some of the food-attracted deer showed malnourished animals with up to 5 pounds of plastic and foil food wrappers obstructing their intestines. In the previously cited Zion National Park study, 24% of the observed hikers fed chipmunks during the control period, even though the park's prohibition on wildlife feeding was widely communicated through roadside signs and messages in the park newspaper, visitor centers, and buses (Marion et al. 2008).

## Close and Rehabilitate the Resource

Management that avoids or minimizes recreation impact is always a primary goal, but sometimes unnecessary trails and campsites are created or impacts occur at unsustainable or sensitive locations or exceed acceptable levels of change. Closure, with unassisted recovery and/or active restoration to achieve natural conditions, is a final strategy in the management toolbox. Some critical precautions are necessary to ensure prevention of recurring use at the closed feature(s) and to ensure that actions will achieve greater spatial concentration of recreation activity on more resistant and sustainably designed trails or sites than within the areas being closed (Figure 6).

Recovery rates are dependent on many factors, including length of growing season, soil texture, fertility, moisture, sunlight penetration, and size of the disturbed area and severity of disturbance (Reid and Marion 2004, Cole 2013b). For example, recovery rates on large highly impacted campsites and trails can be extremely slow in subalpine and alpine ecosystems because of the low rates of plant establishment and growth (Zabinski et al. 2002, Scherrer and Pickering 2006, Willard et al. 2007, Cole 2013b). In contrast, Marion and Cole (1996) found substantial vegetative recovery of moderately impacted campsites and experimentally trampled lanes over 5 years in a Pennsylvania riparian floodplain.

A number of recent studies have evaluated the efficacy of various restoration treatments designed to accelerate recovery processes. Cole (2013b) assessed recovery over 15 years on six wilderness campsites in Oregon's Eagle Cap Wilderness, finding virtually no vegetation cover on control plots that had received no restoration treatments (unassisted natural recovery). Treatments included soil scarification to 15 cm followed by application of several types of organic mulches and locally collected vegetative transplants or seeds. After 3 years about 85% of the transplants had survived, and their growth and cover were significantly greater on plots with organic and compost amendments than on scarified plots. Scarification improved the establishment of volunteer seedlings, but seedling density on seeded plots was more than 5 times higher. A treatment with organic matter and compost soil increased seedling survival during hot, dry periods and enhanced seedling growth; supplemental watering was also critical during


**Figure 6. Restoration of a steep "fall-line" segment of the Appalachian Trail (left) in the popular Roan Highlands area of North Carolina. Restoration work conducted in 2001 included laying native sod excavated from the new side-hill alignment (right) and temporary fencing to discourage use. Geotextile fabric and cellular confinement materials were used, but both surfaced after displacement of the applied gravel. Premixing gravel with native soils is a more natural and sustainable practice.**

the germination period of the first growing season.

Continued assessments over an additional 12 years found that scarification alone yielded plots with only 4% vegetation cover, whereas plots receiving the most effective treatment (scarification, organic and compost amendments, and transplants) had 28% cover compared with 50% in adjacent undisturbed control plots (Cole and Spildie 2007, Cole 2013b). The authors note that study treatments were not very effective for restoring native plant composition; graminoids comprised 69% of the vegetative cover on closed campsites but only 26% on control plots. A similar study was conducted in Idaho's Sawtooth Wilderness, finding that staff-intensive restoration work can reduce recovery times from more than 100 years to several decades (Cole et al. 2012). This study demonstrated the benefits of using larger transplants, fertilization, and watering during dry periods for the initial years.

## Conclusion

Visitor impact management problems will continue to confront wilderness and other protected natural area managers as visitation continues to increase. New longitudinal studies of campsites are describing the cumulative effects of long-term use and impact, providing additional challenges to recreation managers (Cole et al. 2008, Cole 2013a). In response, the land management agencies could do more to increase the capabilities and professional development of their visitor use management staff. The agencies could focus on recreation ecology studies that target sustainability topics, including the relative influence of factors that managers can manipulate to avoid or minimize impacts. Two core challenges will be improving the stewardship and sustainability of our recreation infrastructure and developing and fostering adoption of low-impact outdoor practices and ethics.

Unfortunately, the recreation ecology field of study has long been characterized by exceptionally few full-time scientists, numbering less than 10 worldwide since the first recreation ecologist began his career in 1978. Cole et al. (1987) noted that of 44 recreation ecology articles published from 1980 to 1985, 18 were published by only two authors. The situation is only marginally improved today. Currently, there are six PhD recreation ecologists in the United States, three at universities, two at federal agencies (an National Park Service visitor use management park planner and a US Geological Survey scientist), and one who started a private firm to provide professional consulting and research on trails and visitor impact management.

Recreation ecology research is growing internationally, with a small program of research in Australia and new collaborations between US and Australian scientists. There are also an increasing number of recreation ecology studies published by scientists from other fields of study. A few have focused on sustainability, such as a study by Morrocco and Ballantyne (2007) in the British Isles that investigated footpath morphology and the influence of vegetation and soil type on trail conditions. Another study by Hawes et al. (2013) applied geographic information system (GIS) analyses to predict the sustainability of trails in Tasmania. The recreation ecology field of study is beginning to expand, although US and international support of these studies remains limited, with relatively few of the career paths available to attract new students.

This article sought to review and integrate findings from the field of recreation ecology focused on visitor impact management and carrying capacity. Over time, this research has shifted from an emphasis on use-impact relationships to investigations of additional causal and noncausal factors that influence the nature and severity of recreation impacts. Five core management strategies for avoiding or minimizing recreation impacts in wildland settings were identified to highlight the most effective tools in the visitor impact management toolbox. The most recent recreation ecology research findings were presented and examined to make science-based knowledge more accessible and understandable to planners and managers, who in turn can integrate their professional knowledge and experience to better interpret and apply these results. The new Visitor Use Management framework provides additional guidance to professionalize the process for the continued preservation of natural conditions and processes in our protected natural areas *and* the sustained flow of high-quality recreational experiences.

## Endnotes

1. For more information, see visitorusemanagement.nps.gov/.
2. Use of trade, product, or firm names does not imply endorsement by the US Government.
3. For more information, see www.LNT.org.

## Literature Cited


Anderson, D.H., D.W. Lime, and T.L. Wang. 1998. *Maintaining the quality of park resources and visitor experiences: A handbook for managers.* TC-777, Univ. of Minnesota, St. Paul, MN. 140 p.

Barros, A., J. Gonnet, and C.M. Pickering. 2013. Impacts of informal trails on vegetation and soils in the highest protected area in the Southern Hemisphere. *J. Environ. Manage.* 127:50–60.

Barros, A., and C.M. Pickering. 2015. Impacts of experimental trampling by hikers and pack animals on a high-altitude alpine sedge meadow in the Andes. *Plant Ecol. Diversity* 8(2):265–276.

Bergmann, R. 1995. *Soil stabilizer for use on universally accessible trails.* USDA For. Serv., Publ. 9523–1804-MTDC-P, Technology and Development Program, Beltsville, MD. 14 p.

Brame, R., and D.N. Cole. 2011. *NOLS soft paths: Enjoying the wilderness without harming it*. Stackpole Books, Mechanicsburg, PA. 224 p.

Bromley, M., J.L. Marion, and T.E. Hall. 2013. Training to teach leave no trace: Efficacy of master educator courses. *J. Park Rec. Admin.* 31(4):62–78.

Capacity Work Group: Whittaker, D., B. Shelby, R. Manning, D. Cole, and G. Haas. 2010. *Capacity reconsidered: Finding Consensus and Clarifying Differences.* National Association of Recreation Resource Planners, Marienville, PA. Available online at www.recpro.org/assets/Conference_Proceedings/2010_capacity_reconsidered-whittaker_shelby_haas.pdf; last accessed Jan. 15, 2016.

Christensen, N.A., and D.N. Cole. 2000. Leave no trace practices: Behaviors and preferences of wilderness visitors regarding use of cookstoves and camping away from lakes. P. 77–85 in *Wilderness science in a time of change conference, vol. 4: Wilderness visitors, experiences, and visitor management; 1999 May 23–27; Missoula, MT*. USDA For. Serv., Proc. RMRS-P-15-VOL-4, Rocky Mountain Research Station, Ogden, UT.

Cole, D.N. 1983. *Assessing and monitoring backcountry trail conditions.* USDA For. Serv., Res. Pap. INT-303, Intermountain Forest and Range Experiment Station, Ogden, UT. 10 p.

Cole, D.N. 1989. *Low-impact recreational practices for wilderness and backcountry.* USDA For. Serv., Gen. Tech. Rep. INT-265, Intermountain Research Station, Ogden, UT. 131 p.

Cole, D.N. 1992. Modeling wilderness campsites: Factors that influence amount of impact. *Environ. Manage.* 16(2):255–264.

Cole, D.N. 1993. *Campsites in three western wildernesses: Proliferation and changes in condition over 12 to 16 years.* USDA For. Serv., Res. Pap. INT-463, Intermountain Research Station, Ogden, UT. 15 p.

Cole, D.N. 1995a. Experimental trampling of vegetation. I. Relationship between trampling intensity and vegetation response. *J. Appl. Ecol.* 32(1):203–214.

Cole, D.N. 1995b. Experimental trampling of vegetation. II. Predictors of resistance and resilience. *J. Appl. Ecol.* 32(1):215–224.

Cole, D.N. 1995c. Disturbance of natural vegetation by camping: Experimental applications of low-level stress. *Environ. Manage.* 19(3): 405–416.

Cole, D.N. 1995d. Wilderness management principles: Science, logical thinking, or personal opinion? *Trends* 32(1):6–9.

Cole, D.N. 2004. Impacts of hiking and camping on soils and vegetation: A review. P. 41–60 in *Environmental impacts of ecotourism*, Buckley, R. (ed.). CABI Publications, Wallingford, UK.

Cole, D.N. 2006. Visitor and recreation impact monitoring: Is it lost in the gulf between science and management? *George Wright Forum* 23(2):11–16.

Cole, D.N. 2013a. *Changing conditions on wilderness campsites: Seven case studies of trends over 13 to 32 years.* USDA For. Serv., Gen. Tech. Rep. RMRS-GTR-300, Rocky Mountain Research Station, Fort Collins, CO. 99 p.

Cole, D.N. 2013b. Long-term effectiveness of restoration treatments on closed wilderness campsites. *Environ. Manage.* 51:642–650.

Cole, D.N., L. Dean, D. Taylor, and T.E. Hall. 2012. *Restoration of plant cover on campsites in subalpine forests: Sawtooth Wilderness, Idaho.* USDA For. Serv., Res. Pap. RMRS-RP-99, Rocky Mountain Research Station, Fort Collins, CO. 32 p.

Cole, D.N., and J. Benedict. 1983. Wilderness campsite selection–What should users be told? *Park Science* 3(4):5–7.

Cole, D.N., and T.E. Ferguson. 2009. A relatively nonrestrictive approach to reducing campsite impact: Caney Creek Wilderness, Arkansas. *Int. J. Wildl.* 15(1):20–25.

Cole, D.N., and R.K. Fitchler. 1983. Campsite impact on three western wilderness areas. *Environ. Manage.* 7:275–268.

Cole, D.N., P. Foti, and M. Brown. 2008. Twenty years of change on campsites in the backcountry of Grand Canyon National Park. *Environ. Manage.* 41:959–970.

Cole, D.N., T.P. Hammond, and S.F. McCool. 1997. Information quantity and communication effectiveness: Low-impact messages on wilderness trailside bulletin boards. *Leisure Sci.* 19(1):59–72.

Cole, D.N., and C.A. Monz. 2003. Impacts of camping on vegetation: Response and recovery following acute and chronic disturbance. *Environ. Manage.* 32:693–705.

Cole, D.N., and C.A. Monz. 2004. Spatial patterns of recreation impact on experimental campsites. *J. Environ. Manage.* 70:73–84.

Cole, D.N., and D.J. Parsons. 2013. *Campsite impact in the wilderness of Sequoia and Kings Canyon National Parks: Thirty years of change.* USDI Natl. Park Serv., Natl. Res. Tech. Rep. NPS/SEKI/NRTR-2013/665, Natural Resource Stewardship and Science, Fort Collins, CO. 107 p.

Cole, D.N., M.E. Petersen, and R.C. Lucas. 1987. *Managing wilderness recreation use: Common problems and potential solutions.* USDA For. Serv., Gen. Tech. Rep. INT-GTR-230, Intermountain Research Station, Ogden, UT. 30 p.

Cole, D.N., and D.R. Spildie. 2007. *Vegetation and soil restoration on highly impacted campsites in the Eagle Cap Wilderness, Oregon.* USDA For. Serv., Gen. Tech. Rep. RMRS-GTR-185, Rocky Mountain Research Station, Fort Collins, CO. 26 p.

Daniels, M.L., and J.L. Marion. 2006a. Communicating Leave No Trace ethics and practices: Efficacy of two-day Trainer courses. *J. Park Rec. Admin.* 23(4):1–19.

Daniels, M.L., and J.L. Marion. 2006b. Visitor evaluations of management actions at a highly impacted Appalachian Trail camping area. *Environ. Manage.* 38(6):1006–1019.

Dixon, G., M. Hawes, and G. McPherson. 2004. Monitoring and modelling walking track impacts in the Tasmanian Wilderness World Heritage Area, Australia. *J. Environ. Manage.* 71(4):303–318.

Farrell, T.A., and J.L. Marion. 2002. The Protected Areas Visitor Impact Management (PAVIM) framework: A simplified process for making management decisions. *J. of Sustain. Tourism* 10(1):31–51.

Graefe, A.R., K. Cahill, and J. Bacon. 2011. Putting visitor capacity in perspective: A response to the Capacity Work Group. *J. Park Rec. Admin.* 29(1):21–37.

Hadwen, W.L., W. Hill, and C.M. Pickering. 2008. Linking visitor impact research to visitor impact monitoring in protected areas. *J. Ecotour.* 7(1):87–93.

Ham, S.H., T.J. Brown, J. Curtis, B. Weiler, M. Hughes, and M. Poll. 2009. *Promoting persuasion in protected areas: A guide for managers who want to use strategic communication to influence visitor behavior.* CRC for Sustainable Tourism Pty Ltd., Gold Coast, Australia. 70 p.

Hammitt, W.E., D.N. Cole, and C.A. Monz. 2015. *Wildland recreation: Ecology and management*, 3rd ed. John Wiley & Sons, Hoboken, NJ. 328 p.

Hawes, M., S. Candy, and G. Dixon. 2006. A method for surveying the condition of extensive walking track systems. *Landsc. Urban Plan.* 78:275–287.

Hawes, M., G. Dixon, and R. Ling. 2013. A GIS-based methodology for predicting walking track stability. *J. Environ. Manage.* 115: 295–299.

Heimlich, J.E., and N.M. Ardoin. 2008. Understanding behavior to understand behavior change: A literature review. *Environ. Educ. Res.* 14(3):215–237.

Hendee, J.C., and C.P. Dawson. 2002. *Wilderness management: Stewardship and protection of resources and values*, 3rd ed. The WILD Foundation, Fulcrum Publ., Golden, CO.

Hendee, J.C., G.H. Stankey, and R.C. Lucas. 1990. *Wilderness management*, 2nd ed. North American Press, Golden, CO. 556 p.

Hesselbarth, W., B. Vachowski, and M.A. Davies. 2007. *Trail construction and maintenance notebook.* USDA For. Serv., 0723–2806-MTDC, Technology and Development Program, Missoula, MT. 178 p.

Hill, W., and C.M. Pickering. 2006. Vegetation associated with different walking track types in the Kosciuszko alpine area, Australia. *J. Environ. Manage.* 78(1):24–34.

Hill, W., and C.M. Pickering. 2009. *Evaluation of impacts and methods for the assessment of walking tracks in protected areas.* CRC for Sustainable Tourism Pty Ltd., Queensland, Australia. 23 p.

HOCKETT, K., A. CLARK, Y.-F. LEUNG, J.L. MARION, AND L. PARK. 2010. *Deterring off-trail hiking in protected natural areas: Evaluating options with surveys and unobtrusive observation.* Final Res. Rep., Virginia Tech College of Natural Resources and Environment, Blacksburg, VA. 191 p.

INTERNATIONAL MOUNTAIN BICYCLING ASSOCIATION. 2007. *Managing mountain biking: IMBA's guide to providing great riding*. International Mountain Bicycling Association, Boulder, CO. 256 p.

INTERNATIONAL MOUNTAIN BICYCLING ASSOCIATION. 2004. *Trail solutions: IMBA's guide to building sweet singletrack*. International Mountain Bicycling Association, Boulder, CO. 272 p.

JACOBI, C. 2004. *Monitoring and management of social trails and visitor use on Little Moose Island, Acadia National Park: 1996–2002.* USDI Natl. Park Serv., Nat. Res. Rep. 2004–01, Acadia National Park, Maine. 23 p.

KIM, A.K., D. AIREY, AND E. SZIVAS. 2011. The multiple assessment of interpretation effectiveness: Promoting visitors' environmental attitudes and behavior. *J. Travel Res.* 50(3):321–334.

LAWHON, B., P. NEWMAN, D. TAFF, J. VASKE, W. VAGIAS, S. LAWSON, AND C. MONZ. 2013. Factors influencing behavioral intentions for Leave No Trace behavior in national parks. *J. Interpret. Res.* 18(1):23–38.

LESLIE, E. 1995. Human/wildlife interactions: The effects and consequences. P. 1–3 in *Nature Notes* 11, USDI Natl. Park Serv., Grand Canyon National Park, AZ.

LEUNG, Y.-F., AND J. LOUIE. 2008. *Visitor Experience and Resource Protection (VERP) data analysis protocol: Social trails.* Unpubl. Final Rep., USDI Natl. Park Serv., Yosemite National Park, CA.

LEUNG, Y.-F., AND J.L. MARION. 1999. Spatial strategies for managing visitor impacts in national parks. *J. Park Rec. Admin.* 17(4):20–38.

LEUNG, Y.-F., AND J.L. MARION. 2000a. Recreation impacts and management in wilderness: A state-of-knowledge review. P. 23–48 in *Wilderness science in a time of change conference, vol. 5, 1999 May 23–27, Missoula, Montana*, USDA For. Serv., Proc. RMRS-P-15-VOL-5, Rocky Mountain Research Station, Fort Collins, CO.

LEUNG, Y.-F., AND J.L. MARION. 2000b. Wilderness campsite conditions under an unregulated camping policy: An Eastern example. P. 148–152 in *Wilderness science in a time of change conference, vol. 5, 1999 May 23–27, Missoula, Montana*, USDA For. Serv., Proc. RMRS-P-15-VOL-5, Rocky Mountain Research Station, Fort Collins, CO.

LEUNG, Y.-F., AND J.L. MARION. 2004. Managing impacts of campsites. P. 245–258 in *Environmental impact of tourism,* Buckley, R. (ed.). CABI Publications, Cambridge, MA.

LEUNG, Y.-F., T. NEWBURGER, M. JONES, B. KUHN, AND B. WOIDERSKI. 2011. Developing a monitoring protocol for visitor-created informal trails in Yosemite National Park, USA. *Environ. Manage.* 47:93–106.

LITTLEMORE, J., AND S. BARKER. 2001. The ecological response of forest ground flora and soils to experimental trampling in British urban woodlands. *Urban Ecosyst.* 5:257–276.

MANNING, R.E. 2003. Emerging principles for using information/education in wilderness management. *Int. J. Wildl.* 9(1):20–27.

MANNING, R.E. 2007. *Parks and carrying capacity: Commons without tragedy*, 2nd ed. Island Press, Washington, DC. 328 p.

MANNING, R.E. 2011. *Studies in outdoor recreation: Search and research for satisfaction*, 3rd ed. Oregon State Univ. Press, Corvallis, OR. 448 p.

MANNING, R.E., AND L.E. ANDERSON. 2012. *Managing outdoor recreation: Case studies in the national parks*. CABI, Cambridge, MA. 264 p.

MARION, J.L. 1991. *Developing a natural resource inventory and monitoring program for visitor impacts on recreation sites: A procedural manual.* USDI Natl. Park Serv., Natl. Res. Rep. NPS/NRVT/NRR-91/06, Denver, CO. 59 p.

MARION, J.L. 2003. *Camping impact management on the Appalachian National Scenic Trail.* Appalachian Trail Conference, Harper's Ferry, WV. 109 p.

MARION, J.L. 2014. *Leave No Trace in the outdoors*. Stackpole Books, Mechanicsburg, PA. 128 p.

MARION, J.L., AND C. CARR. 2007. *An assessment of recreation impacts to cliff and rock outcrop environments in Shenandoah National Park.* US Geol. Surv., Final Res. Rep., Virginia Tech Field Station, Blacksburg, VA. 86 p.

MARION, J.L., AND C. CARR. 2009. *Backcountry recreation site and trail conditions: Haleakalâ National Park.* US Geol. Surv., Final Res. Rep., Virginia Tech Field Station, Blacksburg, VA. 92 p.

MARION, J.L., AND D.N. COLE. 1996. Spatial and temporal variation in soil and vegetation impacts on campsites: Delaware Water Gap National Recreation Area. *Ecol. Applic.* 6(2):520–530.

MARION, J.L., R.G. DVORAK, AND R.E. MANNING. 2008. Wildlife feeding in parks: Methods for monitoring the effectiveness of educational interventions and wildlife food attraction behaviors. *Hum. Dimens. Wildl.* 13:429–442.

MARION, J.L., AND T. FARRELL. 2002. Management practices that concentrate visitor activities: Camping impact management at Isle Royale National Park, USA. *J. Environ. Manage.* 66(2):201–212.

MARION, J.L., J.W. ROGGENBUCK, AND R.E. MANNING. 1993. Problems and practices in backcountry recreation management: A survey of National Park Service managers. USDI National Park Service, Nat. Res. Rpt NPS/NRVT/NRR-93/12, Denver, CO. 63 p.

MARION, J.L., AND Y.-F. LEUNG. 1997. *An assessment of campsite conditions in Great Smoky Mountains National Park.* USDI Natl. Park Serv., Final Res. Rep., Great Smoky Mountains National Park, Virginia Tech Field Station, Blacksburg, VA. 127 p.

MARION, J.L., AND Y.-F. LEUNG. 2004. Environmentally sustainable trail management. P. 229–244 in *Environmental impact of tourism*, Buckley, R. (ed.). CABI Publications, Cambridge, MA.

MARION, J.L., AND Y.-F. LEUNG. 2011. Indicators and protocols for monitoring impacts of formal and informal trails in protected areas. *J. Tourism Leisure Stud.* 17(2):215–236.

MARION, J.L., Y.-F. LEUNG, H. EAGLESTON, AND K. BURROUGHS. 2016. A review and synthesis of recreation ecology research findings on visitor impacts to wilderness and protected natural areas. *J. For.* 114(3):352–362.

MARION, J.L., Y.-F. LEUNG, AND S. NEPAL. 2006. Monitoring trail conditions: New methodological considerations. *George Wright Forum* 23(2):36–49.

MARION, J.L., AND S. REID. 2001. Development of the United States Leave No Trace programme: A historical perspective. P. 81–92 in *Enjoyment and understanding of the natural heritage,* Usher, M.B. (ed.). Scottish Natural Heritage, The Stationery Office Ltd., Edinburgh, Scotland.

MARION, J.L., AND S.E. REID. 2007. Minimising visitor impacts to protected areas: The efficacy of low impact education programmes. *J. Sustain. Tourism* 15(1):5–27.

MARION, J.L., AND T. SOBER. 1987. Environmental impact management in the Boundary Waters Canoe Area Wilderness. *North. J. Appl. For.* 4(1):7–10.

MARION, J.L., AND J.F. WIMPEY. 2011. *Informal trail monitoring protocols: Denali National Park and Preserve.* USDI US Geol. Surv., Final Res. Rep., Virginia Tech Field Station, Blacksburg, VA.

MARION, J.L., J.F. WIMPEY, AND L.O. PARK. 2011a. The science of trail surveys: Recreation ecology provides new tools for managing wilderness trails. *Park Sci.* 28(3):60–65.

MARION, J.L., J.F. WIMPEY, AND L.O. PARK. 2011b. *Informal and formal trail monitoring protocols and baseline conditions: Acadia National Park.* USDI US Geol. Survey, Final Res. Rep., Virginia Tech Field Station, Blacksburg, VA. 120 p.

MCAVOY, L., AND D. DUSTIN. 1983. Indirect versus direct regulation of recreation behavior. *J. Park Rec. Admin.* 1:12–17.

MCGUIRE, W.J. 1985. Attitudes and attitude change. P. 233–46 in *The handbook of social psychology*, vol. 2, 3rd ed., Lindzey, G., and E. Aronson (eds.). Random House, New York.

MEYER, K.G. 2002. *Managing degraded off-highway vehicle trails in wet, unstable, and sensitive environments.* USDA For. Serv., Publ. 0223–2821-MTDC, Missoula Technology and Development Center, Missoula, MT. 48 p.

MONLUX, S., AND B. VACHOWSKI. 2000. *Geosynthetics for trails in wet areas*. USDA For. Serv., Publ. 0023–2838-MTDC, Technology and Development Center, Missoula, MT. 23 p.

MONZ, C.A., D.N. COLE, Y.-F. LEUNG, AND J.L. MARION. 2010. Sustaining visitor use in protected areas: Future opportunities in recreation ecology research based on the USA experience. *Environ. Manage.* 45:551–562.

MONZ, C.A., C.M. PICKERING, AND W.L. HADWEN. 2013. Recent advances in recreation ecology and the implications of different relationships between recreation use and ecological impacts. *Front. Ecol. Environ.* 11(8):441–446.

MORROCCO, S.M., AND C.K. BALLANTYNE. 2007. Footpath morphology and terrain sensitivity on high plateaux: The Mamore Mountains, Western Highlands of Scotland. *Earth Surf. Process. Landf.* 33:40–54.

NATIONAL PARK SERVICE. 1997. *A summary of the Visitor Experience and Resource Protection (VERP) framework.* USDI Natl. Park Serv., Denver Serv. Ctr. Publ. NPS D-1214, Denver, CO. 35 p.

NEWMAN, P., R. MANNING, J. BACON, A. GRAEFE, AND G. KYLE. 2003. An evaluation of Appalachian Trail hikers' knowledge of minimum impact skills and practices. *Int J. Wildl.* 9(2):34–38.

NEWSOME, D., S.A. MOORE, AND R.K. DOWLING. 2013. Natural area tourism: Ecology, impacts and management. Channel View Publications, Bristol, UK. 480 p.

OLIVE, N.D., AND J.L. MARION. 2009. The influence of use-related, environmental, and managerial factors on soil loss from recreational trails. *J. Environ. Manage.* 90:1483–1493.

PARK, L.O., R.E. MANNING, J.L. MARION, S.R. LAWSON, AND C. JACOBI. 2008. Managing visitor impacts in parks: A multi-method study of the effectiveness of alternative management practices. *J. Parks Rec. Admin.* 26(1):97–121.

PICKERING, C.M. 2010. Ten factors that affect the severity of environmental impacts of visitors in protected areas. *Ambio.* 39:70–77.

PICKERING, C.M., W. HILL, D. NEWSOME, AND Y.-F. LEUNG. 2010. Comparing hiking, mountain biking and horse riding impacts on vegetation and soils in Australia and the United States of America. *J. Environ. Manage.* 91(3):551–562.

POWELL, R.B., AND S.H. HAM. 2008. Can ecotourism interpretation really lead to pro-conservation knowledge, attitudes and behaviour? Evidence from the Galapagos Islands. *J. Sustain. Tourism* 16(4):467–489.

REID, S.E., AND J.L. MARION. 2004. Effectiveness of a confinement strategy for reducing campsite impacts in Shenandoah National Park. *Environ. Conserv.* 31(4):274–282.

REID, S.E., AND J.L. MARION. 2005. A comparison of campfire impacts and policies in seven protected areas. *Environ. Manage.* 36(1):48–58.

ROOVERS, P., K. VERHEYEN, M. HERMY, AND H. GULINCK. 2004. Experimental trampling and vegetation recovery in some forest and heathland communities. *Appl. Veg. Sci.* 7(1):111–118.

SCHERRER, P., AND C.M. PICKERING. 2006. Recovery of alpine herbfield on a closed walking track in the Kosciuszko Alpine Zone, Australia. *Arctic Antarctic Alpine Res.* 38(2):239–248.

STANKEY, G.H., D.N. COLE, R.C. LUCAS, M.E. PETERSEN, AND S.S. FRISSELL. 1985. *The limit of acceptable change (LAC) system for wilderness planning.* USDA For. Serv., Gen. Tech. Rep. INT-176, Intermountain Research Station, Ogden, UT. 37 p.

STEWART, W.P. 1989. Fixed itinerary systems in backcountry management. *J. Environ. Manage.* 29(2):163–171.

VAGIAS, W.M., R.B. POWELL, D.D. MOORE, AND B.A. WRIGHT. 2014. Predicting behavioral intentions to comply with recommended Leave No Trace practices. *Leisure Sci.* 36(5):439–457.

WAGAR, J.A. 1964. *The carrying capacity of wildlands for recreation*. For. Sci. Monogr. No. 7, Society of American Foresters, Washington, DC. 23 p.

WHINAM, J., AND N.M. CHILCOTT. 2003. Impacts after four years of experimental trampling on alpine/sub-alpine environments in western Tasmania. *J. Environ. Manage.* 67(4):339–351.

WHITTAKER, D., S. SHELBY, R. MANNING, D. COLE, AND G. HAAS. 2011. Capacity reconsidered: Finding consensus and clarifying differences. *J. Park Rec. Admin.* 29(1):1–19.

WIDNER, C.J., AND J.R. ROGGENBUCK. 2000. Reducing theft of petrified wood at Petrified Forest National Park. *J. Interp. Res.* 5(1):1–18.

WILLARD, B.E., D.J. COOPER, AND B.C. FORBES. 2007. Natural regeneration of alpine tundra vegetation after human trampling: A 42-year data set from Rocky Mountain National Park, Colorado, USA. *Arctic Antarctic Alpine Res.* 39(1):177–183.

WIMPEY, J., AND J.L. MARION. 2010. The influence of use, environmental and managerial factors on the width of recreational trails. *J. Environ. Manage.* 91:2028–2037.

WIMPEY, J., AND J.L. MARION. 2011. A spatial exploration of informal trail networks within Great Falls Park, VA. *J. Environ. Manage.* 92:1012–1022.

WINTER, P.L. 2006. The impact of normative message types on off-trail hiking. *J. Interp. Res.* 11(1):34–52.

ZABINSKI, C.A., T.H. DELUCA, D.N. COLE, AND O.S. MOYNAHAN. 2002. Restoration of highly impacted subalpine campsites in the Eagle Cap Wilderness, Oregon. *Restor. Ecol.* 10:275–281.