Integrative Research in the Sociology and Ecology of Outdoor Recreation

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Abstract

The issues and concerns facing recreation managers, academicians, and other practitioners are now often complex and important enough that solving them requires more than the sum of parts from social and physical disciplines. To that end, this dissertation document identifies and addresses three research projects that in varying proportions draw from the social and ecological aspects of recreation management.

The first of three articles in this dissertation examined approximation of cross sectional soil profiles on foot trails. Monitoring this ecological indicator with current field techniques can be expensive and time-consuming for managers. Therefore, this article described a modified procedure for assessing trail soil loss and discusses several potentially useful geometric curves for approximating the cross-section of a trail at a given sampling point and in aggregate across a trail network. Differences in profiles for each study area and implications for inventorying and monitoring were discussed.

The second article examined integration of soundscape and hiker spatial modeling. GPS data were used to generate a spatial model of hiker travel, soundscape modeling software calibrated with field data was used to generate a spatial model of sound, and the models were integrated in a geographic information system to provide insights for baseline and an alternative management option scenario. The findings suggested that small changes in soundscape, based on altered management practices, can have large effects on visitors' hiking experiences in terms of soundscape.

The third article discussed an observational study examining several integrative and additive, information/education and site management approaches to preventing natural resource damage along backcountry trails. Video surveillance equipment unobtrusively captured hiker behaviors within the study area for each treatment. The findings suggested that direct, obtrusive measures (e.g., low symbolic rope fencing) in some cases can outperform multiple concurrent measures that are less direct and/or obtrusive. Implications on aesthetics, experiences, and management decision-making were discussed.

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Introduction and Review

An irreducible truth of recreation management was captured early in the evolution of the discipline by Frissell (1963), who stated that all recreationists change [and are changed by] the environment and experiences involved in their recreation. All the rest, as a saying goes, is bookkeeping. The bookkeeping, however, is the important and still-developing aspect of recreation management, where researchers and managers attempt to quantify the effects and changes caused by recreationists on themselves and their physical and social environments. Out of the need to improve the quantification of effects and changes in recreation management, two primary academic disciplines have grown: recreation ecology and recreation sociology. The former, recreation ecology, seeks to apply a biophysical lens to understand changes brought about through recreation (Hammitt and Cole 1998, Leung and Marion 2000). The latter, recreation sociology, views the recreation world through social and experiential understanding. Together, these disciplines present insights on the tangible and intangible faces of recreation management. This dissertation presents three research projects that rely on combining the worldviews espoused by the twin disciplines of recreation ecology and sociology. To understand the role and importance of these research projects within their broad context, however, it is important to understand the evolution of recreation management from its biology-based beginnings, through the rise of social science in recreation research, to the integrative approaches of the current day, using carrying capacity and recreation impacts as uniting themes and scopes.

Roots of Recreation Management

Modern recreation management began as a biologically-focused endeavor. In the decades prior to 1900, hunting for the sake of leisure, trophies, market pelts and an inexpensive food supply reached a scale that, alongside exogenous disease sources, eradicated some entire species (e.g., passenger pigeons) and decimated the populations and effective ranges of many others (e.g., large ungulates in the eastern United States). These practices were reflective of the American mindset at a turning point in the nation's history: the closing of the American western frontier with the 1893 census and the concomitant realization that the country's natural resources were exhaustible. Justified alarm at these rapidly proliferating resource depletions provided the basis for the formation of wildlife biology and the conservation and preservation movements, headed by first head of the Forest Service Gifford Pinchot and Sierra Club savant John Muir, respectively (Runte 1997). Within a few decades following the establishment of the U.S. National Park Service in 1916, researchers including Aldo Leopold were actively developing projects to understand the dynamics of wholesale destruction of species in the name of recreation (National Park Service Organic Act §1, 1916). In 1934, Leopold expressed concern that consumptive recreation (i.e., non-subsistence hunting) and government predator eradication programs could harm the environment at profound, even landscape scales. This attention to landscapes' ability to sustain wildlife vis-à-vis recreation and other extractive practices was a first attempt at articulating the key recreation management concept of carrying capacity (CC). Leopold defined CC as "the most of a species a range or habitat can accommodate" (Dhondt 1988). His contemporary, Sumner (1936) was among the first to apply the idea in human terms, asking, "How large a crowd can be turned loose in a wilderness area without destroying its essential qualities?"

Early calls for resource stewardship from the likes of Sumner, Leopold, and later his son, A. Starker Leopold (1963 Leopold Report) suggest that the initial forms of recreation management were centered on charismatic wildlife species, such as wolves and large ungulates. It was not until a contemporary of the younger Leopold, J. A. Wagar, published a seminal 1964 report on post-WWII era crowding in parks, that recreation management substantively began the slow shift in focus toward recreationists first heralded by Sumner three decades before. Even so, CC studies informing management practices in the 1960s and early 1970s tended to conceptualize recreationists as simply a special case animal, subject to numerical CC in any given setting. In these studies, focus was on the subset of ecological changes caused by recreation that were considered depreciative ("impacts"). Specifically, Wagar's influence on the field was to import from wildlife biology the idea of numeric human CC. Less than two decades later, the 1978 National Parks and Recreation Act P.L. 95-625 required explicit CCs within park general management plans. The concept seemed usefully parsimonious at first, leading to an easily managed model for limiting recreational impacts. The model stated that increasing human recreation use and increasing impacts share some monotonically positive relationship (Figure 1-1). By determining a maximally acceptable level of impacts (Y) and extrapolating through the trend to the associated use level (X), a maximum use level could be established and managed.

This model neatly tied together what were considered at the time the three primary factors of recreation dynamics: use levels, ecological preservation/conservation, and management approach. To protect the biota, managers would control use levels by throttling at the gate access to recreation areas. Recreation ecology, however, entered its adolescence as a discipline by calling into question the assumptions driving this basic model.

Emergence of Recreation Ecology

A variety of studies (e.g., Allcock 1973, Bell and Bliss 1973, Boorman and Fuller 1977, Cole et al. 1987, Hammitt and Cole 1998, Cole and Marion 1988, Marion and Cole 1996) strongly suggested a key refinement to the basic use/impact conceptual model. They posited that the use-impact relationship was not a simple linear one, or uniform across the many components of an ecosystem susceptible to recreation impacts. In most cases, the trend line was instead some variant on a sigmoidal (s-shaped, asymptotically approaching unity) curvilinear relationship

(Figure 1-2). The great complexity and interrelatedness of recreation impacts makes the simple, single linear relationship ineffective as a management tool. To further complicate matters, the social/use aspects of recreation add layers of complexity for management. Varying kinds of recreation (e.g., mountain biking vs. ORV use) and seasons of use exert markedly differential pressures on vegetation, soils, and wildlife. Even the same type of use can be engaged in with different behaviors ranging from low to very high impact. New kinds of equipment also change the ways in which people interact with the recreation setting (e.g., camp stoves vs. campfires). An important management strategy arose from the refined use-impact dynamic: 1) dispersing use where use levels were sufficiently low to avoid exceeding a resource's inherent resistance to impacts, and 2) concentrating use onto already-impacted, durable, or hardened areas where use levels overwhelmed resource resistance and resilience capacities (Cole 1995, Reid 2003).

Vegetation Impacts

The revised model suggested a given species or biological community, given some varying degree of resistance to impact, could absorb very low levels of recreation pressure and rebound without lasting degradation (Figure 1-2, left end of trend lines) (Leung and Marion 1996). With increasing levels of recreation traffic, however, that resistance could quickly become overwhelmed (Hammitt and Cole 1998, Leung and Marion 2000). Dramatic changes in vegetation composition or loss could occur among species with low trampling resistance (e.g., forest species with tall stems and broad leaves, Figure 1-2, left-most trend line). More-resistant low-growing species with non-woody growth forms, including grasses, sedges, and some prostrate herbaceous plants could tolerate much more use before succumbing (Figure 1-2, middle trend line) to recreation pressure (Hammitt and Cole 1998, Cole 1995, Marion and Cole 1996). Highly resistant species,such as larger trees and shrubs, could sustain high levels of recreation use, in some cases indefinitely (Figure 1-2, right-hand trend line). These trend lines would also shift based on climate variations, e.g., a period of dry years making vegetation more sensitive, or a series of harsher winters that lowered reproductive success among animal populations. Early recreation ecologists expanded the impact model beyond vegetation loss. They discovered that low levels of recreational traffic in deciduous forest settings lead to compositional and species richness changes, as trampling-susceptible species are gradually replaced by smaller numbers of trampling-tolerant species (Frissell and Duncan 1965). Higher levels of recreational traffic will eventually overwhelm the more resilient species as reproduction is halted and plant nutrients are channeled into tissue repair. Eventually trampled areas suffer reduced biomass and vegetative cover (Cole 1995; Sun and Liddle 1993).

Soil and Water Impacts

As vegetation cover is lost, continued traffic exposes soils by pulverizing surface organic matter, which when present cushions soil from impact, but when pulverized is easily removed by wind or overland water flow. Once exposed to visitor trampling, macropore and micropore spaces in the soil are reduced as soil is compacted. This change in soil structure results in reduced water infiltration rates, thereby increasing overland flow volume and velocity. Surface runoff accelerates, able to carry larger particles longer distances, leading to sheet erosion on campsites and channelized erosion along trails in a positive feedback cycle (Monti & Mackintosh 1979). At this stage, recovery to an “unimpacted” state can require tens or hundreds of years in some places. Skilled trail design and construction minimize these impacts to narrow, sustainable corridors by avoiding poorly drained areas, traversing steep topography with low grades or stonework, and including functional drainage features.

In wetter settings, channelization in swampy areas can alter hydrologic regimes on a large scale, altering microenvironments substantially for sensitive and/or endemic plant species. Soil particles transported into streams and larger waterways increase turbidity, lead to substantial deposition, or and in some cases can scour streambed habitat crucial to macroinvertebrate survival or reproduction. In addition, overland flow can easily transport pathogens derived from improperly disposed visitor or pack animal waste, including *E. coli*, *Cryptosporidium*, and *Giardia l.*, into channel sediments, where they can remain dormant for years and be agitated back into the water column by footfalls or rain events. In higher altitude bodies of water where low discharge/ recharge rates lead to protracted residence times, accumulation of sweat electrolytes, sunblock, detergents, food particles and other waste chemicals can produce adverse conditions for highly sensitive alpine aquatic species. Finally, transportation of recreational watercraft from one body of water to another can introduce exotic species including aggressive invasives like zebra mussels (*Dreissena polymorpha*) in the northeastern United States and throughout Europe.

Wildlife Impacts

Wildlife species are also susceptible to impacts derived from recreation. Reclusive species that are sensitive to human presence can be easily disturbed from foraging or reproductive behaviors. For example, loons (*Gavia spp*.) in the northeastern United States are routinely displaced from nest clutches by unwary boaters. Such events can lower reproductive success by allowing developing eggs to cool while the nesting parent flees contact with humans. Some species, however, adapt to human presence, becoming habituated to non-threatening disturbances and minimizing flight behaviors (Figure 1-3). For species that pose little danger to humans, this effect is desirable as it minimizes impacts to the species. In some cases habituation can become extreme, with wildlife developing food conditioning behaviors due to human food scavenging opportunities (Marion, Dvorak and Manning 2008). While opportunities to feed habituated squirrels and seagulls are attractive to some recreationists, this situation can constitute grave danger to the recreationist and his/her property (e.g., food-conditioned bears at Yosemite National Park destroying vehicles for food stored inside), as well as to the animal (e.g., deer at

Grand Canyon National Park developing fatal gastric blockage from eating plastic food wrappers made available by careless hikers). In addition to direct interaction with recreationists, wildlife can suffer from indirect impacts, including habitat fragmentation from roads or trails. Holmquist and Schmidt-Gengenbach (2002) have demonstrated that trails dissecting meadows at Yosemite National Park dramatically alter edge: core habitat ratios and fragment habitat to the extent that some ants (*Hymenoptera spp*.) show reduced or eliminated propensity to cross human foot trails.

Taken together, all of these dynamics suggest that, depending on the species, setting, use type, climate, and management approach; a wide range of use levels (X1 – X3, Figure 1-2) could lead to the same level of impact for a particular recreation setting. The notion of protecting protected natural area ecosystems by restricting visitation to a static numeric carrying capacity was rendered obsolete.

Modern Recreation Ecology

The catalogue of physical impacts provides the rationale for the wide variety of management approaches available to land management agencies today. Once-crude numerical carrying capacity is made more nuanced to include managerial interventions to improve capacity by hardening the resource, changing impactful aspects of use through education or regulation, and/or dispersing the impact more widely in space or time (Seidl and Tisdell 1999).

Recreation ecology facilitates wise management of another use-based issue: differing modes of recreation. Managers need to understand that impacts vary greatly among, for example, modes of travel (Hammitt and Cole 1998, Lull 1959). Consequently, management techniques can be much more effective through targeting depreciative actions of specific user types. For example, differential degrees of trail hardening for areas zoned for horsepackers versus backpackers provides better resource protection while potentially supporting more recreationists than a traditional combined-use approach. The trail and carriage road system at Acadia National Park is one particularly effective example.

A third and comparatively new use-associated issue informed by recreation ecology is the general spatial arrangement of use impacts. Acting as a bridge to physical geography research, recreation ecology suggests a characteristic spatial pattern of impact, described by Manning (1979) (Figure 1-4). A refinement on this idea helps managers to anticipate impacts according to spatial decay surfaces from attraction and access points.

Finally, managers are aided by modern recreation ecology research through an improved understanding of the crucial distinction between acceptable vs. unavoidable impacts (Watson et al. 2000). The old model's quantification of absolute impact is not a useful concept to managers. For example, the original trail network at Acadia National Park included multiple direct-ascent trails to each peak on the island. We now understand this to be an avoidable impact situation in two dimensions-- direct ascent trails create needless erosive conditions, and multiple routes to each peak are redundant.

For all these reasons, recreation ecology is playing a key role in replacing traditions of park and protected area managers with defensible, empirically verified approaches integrating examination of the use, management, and environmental factors of recreation impacts. However, recreation ecology cannot be considered complete without an understanding of the sociology of recreation and how it has also shaped recreation management as a field of study.

Recreation Sociology

The dual mandate of the National Park Service (National Park Service Organic Act §1, 1916) established a precedent for all other U.S. land management agencies: perpetually protect the resources engaged for recreation purposes but provide quality outdoor recreation opportunities despite the inevitable associated impacts. Recreation ecology describes one side of this tension: "what are the biophysical impacts caused by recreation?" and attempts to prevent or minimize these impacts. The recreation sociologist attempts, among other tasks (e.g., understanding place attachment, experience-use history, and specialization), to understand the complementary concept: "what are the experiential impacts caused by various aspects of recreation?" It is beyond the scope of recreation ecology to examine the social impacts of recreation: diminished experiences via crowding and conflict (Manning 1999, Vaske and Donnelly 2002). Similarly, the effects of these impacts (coping behaviors including displacement, product shift, and rationalization) are characterized through sociological methods including unobtrusive observation, quantitative questionnaires, and qualitative interview instruments.

For example, the recreation ecologist confronts the impacts to vegetation, soil, water, and wildlife when a group of thirty travels cross-country without implementing Leave No Trace principles. The recreation sociologist asks, "*why* do they want to go off-trail in the first place?" and, "what is the experiential loss if they are not permitted to go off-trail, or if they encounter resource degradation as a result of others having gone off-trail?" and, "how can visitors successfully be encouraged to remain on trail, minimizing impacting depreciative behaviors, without feeling too 'managed'?" Similarly, sociological inquiries provide managers with the understanding necessary to wield depreciative behavior-limiting management techniques (e.g., fencing, low rock trail borders, information/educational signage, and uniformed employee presence) appropriately within a given context (e.g., frontcountry or backcountry trail setting) (Cheung 1972, Manning 1999, Park et al. 2008). It is important for managers to understand the social effects of their decisions, as they can strongly affect important experiential indicators, such as perceptions of crowding and perceptions of management obtrusiveness (Shelby Vaske and Heberlein 1989, Carls 1974). This crowding example illustrates another useful insight of recreation sociology: descriptive physical characteristics of a recreation setting (e.g., use level) are related to but not the same as their evaluative characteristics (e.g., perceptions of crowding) and can be managed quite differently (e.g., distributing a constant use level across space and time to reduce perceptions of crowding) (Manning 1999). In the preceding example, this distribution can be effected through a variety of means and mapped to a spectrum of indirect – direct management actions. Indirect, usually information/education-based actions, are generally preferred by managers as they are thought to be less obtrusive to visitor experiences (Roggenbuck and Berrier 1982). Several theories have emerged in the literature that may enhance the effectiveness of messages designed to cause or modify specific recreation behaviors.

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A Selection of Theories Used for Enhancing Message Effectiveness

Ajzen's (1985) Theory of Planned Behavior (TPB), a refinement of the earlier Theory of Reasoned Action, attempts to understand behavioral decision-making at an individual level. The proposed mechanism is that behaviors are driven by individuals' decisions, which are in turn governed by attitudes, subjective norms, and perceived behavioral control. This theory has come under some criticisms for requiring managers to exert direct control over behaviors in some cases, and for failing to address how behaviors are executed in favor of simply addressing if a behavior is undertaken or not (Brown 1999). A recent study by Reigner et al. (2009) found the TPB to be generally explanatory in understanding visitor decision-making processes (and how management interventions affected the process's related attitudes, subjective norms, and perceived behavioral control) relating to swimming or refraining from doing so at a popular but somewhat dangerous swimming area in Maui.

A second potential means of enhancing message effectiveness is the Elaboration Likelihood model (Petty and Cacioppo 1986). Specifically, the "route to persuasion" construct within this model examines how messages are evaluated by people on the bases of content and/or delivery (Manning 1999, 2003; Park et al. 2008). However, some disagreement exists between researchers as to the proposed link between attitudes and behaviors, as studies have suggested that the links involved are situation-specific (Manning 1999). In a recreation management context, an emphasis on delivery might involve a uniformed ranger asking visitors to remain on the paved trail. In this case, the official presence of the ranger, even if expensive to staff, would lend credence to the message more effectively than could a sign bearing an equivalent message. By the same token, a more formal or prominently placed sign by itself communicates a stronger message than a less formal one with identical wording (Baldwin and LaPage 2002).

A third potential means of enhancing message effectiveness is application of Norm Activation Theory to environmental management (Stern et al. 1986). It posits that awareness of consequences (e.g., resource degradation as a result of recreation activities) and ascription of responsibility for consequences (e.g., "your footsteps have caused trampling damage to plants along this trail") drive moral decision-making. The shortcomings of this construct are its assumptions that visitors are 1) aware of the impacts of their behaviors on physical and experiential resources and 2) that they care (or can be made to care) enough about these to modify behaviors.

A fourth way to augment message effectiveness may be found in the Stages of Moral Development model (Kohlberg 1976). This theory has been disputed in the literature on grounds of possible gender bias but still provides a potentially useful means through which managers may come to understand aggregate visitor behavior (Walker 1984, Gilligan 1982, Gilligan and Attanucci 1994). In essence, visitors will tend to respond most effectively to management messages and other efforts partially based on degree of moral development. For example, a visitor with a low ("pre-conventional") level of moral development might best respond to messages that clearly outline rewards or punishments based on compliance with management efforts. Threat of a fine for noncompliant behavior is a common example. More morally developed visitors would theoretically respond better to messages emphasizing that members of their groups or others would view them positively when in compliance. Highly morally developed visitors may respond best to appeals to the sense of justice or broad ethical notions (e.g., "Please join in to ensure that this area is protected for the enjoyment of our future generations!") (Kohlberg Levine and Hewer 1983). Thus, it may be useful to gauge moral development among visitors in order to target messages or combinations of messages suitably (Manning 2003).

Despite the proliferation of theoretical knowledge on enhancing message effectiveness, in areas of more significant resource or experiential degradation, more-direct techniques or combinations of direct and indirect techniques generally may be more effective at influencing visitor behaviors (Johnson and Swearingen 1992, Roggenbuck and Berrier 1982, Park et al 2008). This is one important area in which recreation ecology and sociology are best considered together for effective recreation management.

Integrating Ecology and Sociology

At its core, the value of integrating ecological and sociological approaches to understanding recreation rests in being able to understand and evaluate the objective (i.e., ecological) and subjective/evaluative (sociological) aspects of recreation (Manning 1999). Each is important, but cannot capture all key concerns for managers by itself. Integrating these fields acknowledges the dual mandate of the park Service, resource protection and visitor experience (Reid 2003).

An objective evaluation of an ecological impact of recreation (trampling) is not equivalent to its subjective evaluations by visitors (perceived crowding and perception of erosion). To nuance it further, the recreation ecologist provides a quantitative, numeric assessment of a situation. The sociologist provides multiple visitor perspectives, aggregate visitor perspectives ("social norm-like" crystallization of opinion), and contrasts these with managment perspectives. In the context of CC, the integrated socio-ecological approach brings together the separate factors necessary to understand the capacity for a given recreation opportunity: 1) use-related factors (type and amount of use, group size, and visitor behavior), 2) environmental factors (resistance and resilience of vegetation and soil, topography, season, and spatial distribution of use), and 3) managerial factors (facility design, construction, maintenance, regulations, and educational programs).

A further illustration of the complementary nature of recreation sociology and ecology is the case of informal (visitor-created) trail network proliferation and management. Without the sociological lens to understand the motivations of trail-creating visitors (and their tendencies to adopt direct approach, least-cost path routing), the ecologist cannot effectively suggest appropriate management actions to mitigate the problem (Rees 2004). For example, visitors to a popular and well-used area of Potomac Gorge, C & O Canal National Historic Park, exhibit a high degree of place attachment and resource specificity. These visitors will tend to respond differently to educational and site management actions versus a first-time visitor in the same place (Marion and Hockett unpublished data). As a result, site management actions become much more important, as do personal contact-based approaches, when trying to deter off-trail travel.

In sum, the two disciplines require each other to effectively support sustainable management of protected areas. What is considered the most effective management approach by recreation ecologists might not be considered the most acceptable by recreationists, a determination usually made by recreation sociologists (Jubenville 1995). Thus, working in concert, the ecologist and the sociologist provide a balanced, detailed and nuanced perspective on recreation management research and its implications for protected area managers.

Adaptive Management

The formal context in which recreation sociology and ecology can be brought together to address recreation management problems is adaptive management (Grumbine 1994, Cortner and Moote 1999). First developed in industrial operations planning, adaptive management was a response to the rational comprehensive planning philosophy previously used in recreation management (Johnson 1999, Reid 2003, Holling 1978, Walters 1986). While rational comprehensive planning placed emphasis on the contributions of science to managing wildlands, the approach proved to be too inflexible and linear to adequately accommodate the complexity and dynamism inherent in natural systems. As a result, adaptive management was fitted to the needs of recreation managers and agencies by virtue of being "deliberately experimental, flexible, and actively adaptive" (Reid 2003). As technology developed alongside the changing philosophies of recreation planning, computer simulation modeling began use to enumerate adaptive management alternatives for developing social and biological CCs before deploying them in the field (Lawson et al. 2002). As adaptive management gained acceptance and began to supersede rational comprehensive planning approaches among practitioners, formal recreation planning frameworks were developed to provide structure and consistency to adaptive management programs within recreation agencies.

Planning Frameworks

Fifteen years after A. Starker Leopold and Wagar's key publications, the 1978 National Parks and Recreation Act P.L. 95-625 required explicit carrying capacities within park general management plans. Soon after, formal recreation planning frameworks began to emerge one after the other, all of which to varying extents grappled with the idea of numeric CC and attempted to make planning more transparent and accountable (Goetz Phillips and Randolph 2000). In the United States, Limits of Acceptable Change (LAC) (Stankey et al. 1985, Stankey et al. 1984) and Visitor Impact Management (VIM) (Graefe et al. 1990) gained early prominence, particularly with use by the US Forest Service. By this point though, the idea had emerged that recreation limits were more subtle and nuanced than simply a maximum number of bodies in one place at a time. Numerical amount of use was recognized as only one of several key determinants of recreation quality (Cole et al. 1987).

The National Park Service began development of its planning framework, Visitor Experience and Resource Protection (VERP) in 1992 (National Park Service 1997). First applied at Arches National Park (Manning 2004, Manning et al. 1995), it was formally published in 1997. As the state of recreation management advances and legal requirements evolve, CC was recently redefined by the Park Service at the Yosemite Carrying Capacity Symposium as

> the type and extent of visitor use an area can sustain while maintaining acceptable resource and visitor experience conditions that fulfill the purpose of the park. To simplify, user capacity has to do with what people do in a park, where they do it, and what impact their activities have on park resources and the experience of other visitors.
>
> (National Park Service 2008)

Guidance for a parallel planning framework, LAC, illustrates the above principle, stating that "a limit should be placed on the amount of change to be tolerated. When a site has reached this predetermined limit of deterioration, steps should be taken to prevent further adverse change" (Frissell 1963). That is, for these planning frameworks, broad prose management goals are drafted by park planners to reflect the overall values for which a protected area is being managed (Cole and Stankey 1997). Those broad goals are translated into a variety of indicator variables. Manning (1999) describes them as measurable, manageable, sensitive, affordable, and important variables that each quantify some real world phenomenon as a proxy for some component of the management goals. Typically, these variables can be used to measure physical characteristics or social characteristics (e.g., encounters along a trail per day, trail condition class, etc.).

Once indicator variables are established, they are assessed for baseline data and used to inform the selection of standards of quality. Standards reflect the numeric values at which an indicator has reached an unacceptable level, such as too much erosion or too many people visible at one time at an attraction site. The values are set according to management goals, expert opinion, and on visitor feedback through surveys. Surveys provide key quantitative data about value judgments (i.e., where "some impact" becomes "too much") through the use of stated choice analyses, norm curves, and other related techniques. A good standard is quantitative and expressed as a percentage to account for inevitable, rare, and unpredictable perturbations in indicator value. For example, if one indicator for a picnic area's experiential quality includes "number of other groups encountered in the area," the standard generally is expressed in a way that accommodates the few dates a year during which occupancy of the site usually spikes, e.g., during national holidays.

Indicators are monitored periodically and when they are found to have exceeded their standards, predetermined management action is taken. If the management action is determined to be inadequate or inappropriate (e.g., due to changing management needs or resource conditions), the process can be revised as a matter of adaptive management. It should be noted, though, that problems with the indicators and standards approach to adaptive management include prohibitive monitoring costs over time, since in many cases, monitoring is undertaken with no explicit sunset or expiration (Lee 1999).

Relation of Recreation Management to This Dissertation

To varying degrees, each of the research projects described in this document relate to indicators and standards of quality. Specifically, the first paper explores alternative methods of collecting data pertaining to a common physical indicator variable used in the management of trail networks: cross sectional soil loss. As trails are eroded and compacted, a cross-sectional area (CSA) is exposed beneath where the original trail surface once was, though in low-lying areas, soil can accumulate above a tread surface. Periodic characterization of CSA across a trail network is a useful and important indicator of trail system condition but is labor-intensive. Therefore, this article seeks to improve the time required for accurate measurements of CSA indicator data through mathematical generalization. The value for the research community is the initial effort at identifying region-specific and generalized geometric models of CSA profile shape. This understanding provides opportunity for further research on the variables that strongly influence soil profile shape, potentially including: soil series, use type and level, climate, topography, soil texture, and soil cohesion.

The second paper investigates hiker exposure to transportation noise at Rocky Mountain National Park (RMNP). Shuttle transportation amenities there are undergoing review for potential expansion. However, the addition of more busses (and consequent reduction in personal vehicles) could potentially alter the soundscape environment for the trail system surrounding the road in the study area. As the opportunity to experience natural quiet is an important component of hikes at RMNP, spatial modeling is used to estimate the effects on multiple experiential indicators of two transportation management alternatives. The value to the research community is demonstration of integration of spatialized visitor use data with soundscape simulation, and exploration of potential indicators of soundscape experience, which to date have not been well explored in the literature.

The third article in this dissertation, unlike the previous two, does not deal directly in measurement or prediction of data for one or more indicator values. Instead, it is a quasi-experimental observational investigation of combinations of management techniques designed to encourage visitors to stay on trail near a fragile and degraded biological community in Acadia National Park, Maine. Here the connection to indicators and standards is through the condition of the resources along the trail, and the condition of the trail itself as a result of many years of intensive visitor use. The management techniques studied have the potential to improve the values of common resource condition indicators (informal trail proliferation and vegetation and soil damage) by modifying visitor behaviors. The value of this paper to the research community is its exploration of additive and integrated site management and educational alternatives. Most studies of this nature are attitudinal, hypothetical, and deal only with individual rather than combinations of management techniques.

Figures

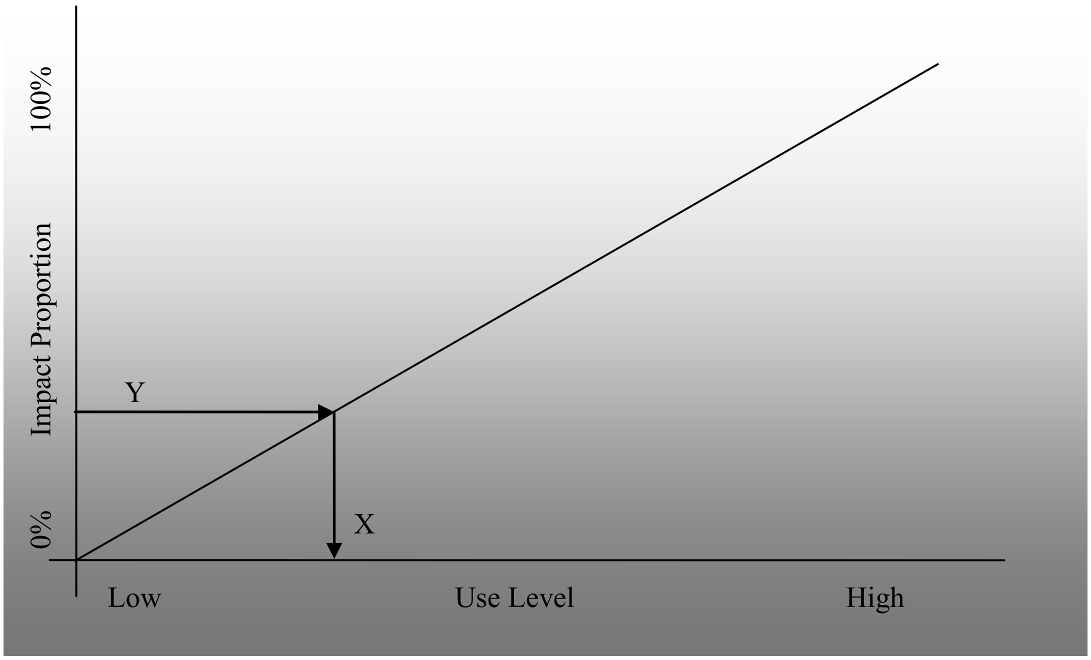

Figure 1-1. General use-impact relationship. Adapted from Manning 1999.

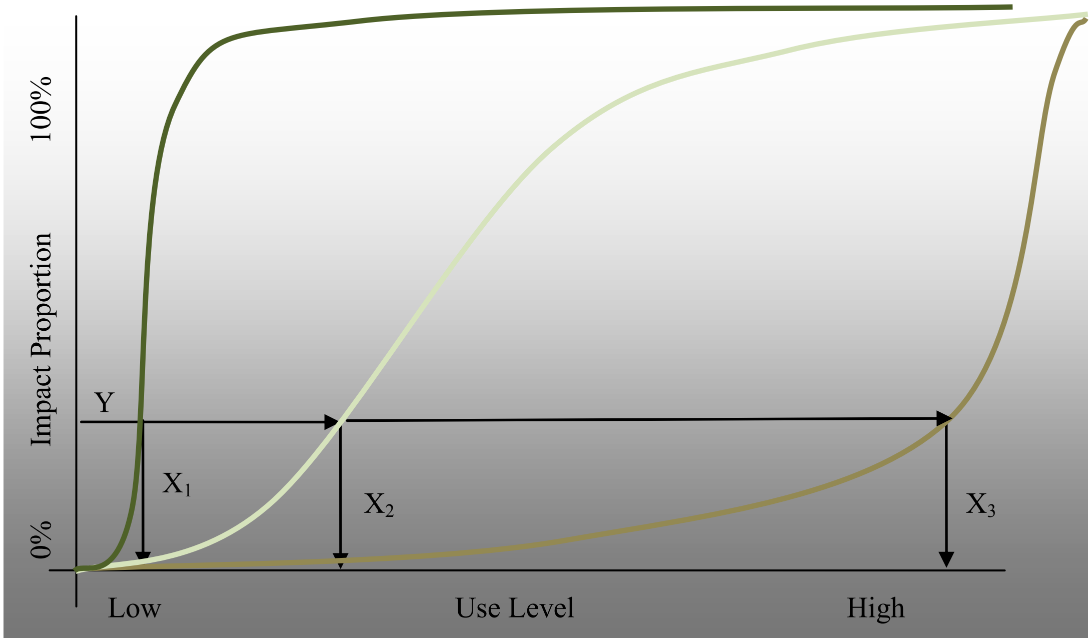

Figure 1-2. General use-impact relationship. Adapted from Hammitt and Cole 1998.

Figure 1-3. Composited image of coyote and recreationists, Denali National Park.

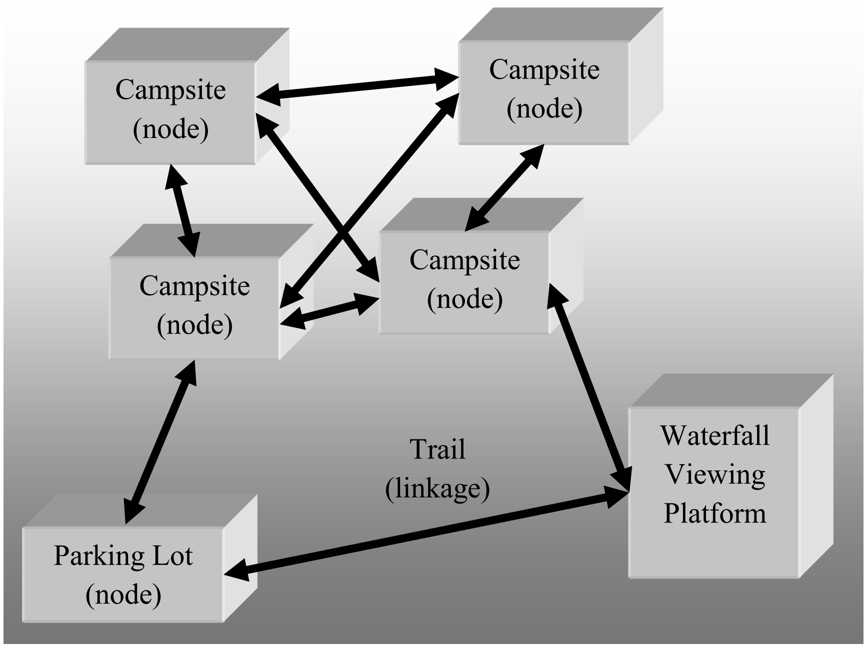

Figure 1-4. Schematic diagram of node and linkage distribution of impacts at a protected area. Adapted from Manning 1979.

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Dissertation Structure

The overall theme of this dissertation is integrated research in recreation ecology and sociology. The format includes three journal articles, 1) Foot Trail Cross Section Modeling: Approximation, Accuracy, and Implications for Trail Network Inventory and Monitoring 2) Application of Sound and Spatial Modeling to Visitor Experience Management at Rocky Mountain National Park and 3) Efficacy of Indirect and Site Management Techniques in Reducing Off-Trail Behavior in a Fragile Biotic Community, Acadia National Park. Summary findings and conclusions are contained within each article and are not restated at the conclusion of the dissertation due to the widely varying content areas across articles.

Modeling Cross-Sectional Area Profile Shape on Trails: Approximation, Accuracy, and Implications for Trail Network Inventory and Monitoring

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ABSTRACT

Trail impact assessment and monitoring (IA&M) are key programs in protected area resource management. By providing protected area managers with quantitative resource condition data over time, monitoring helps to identify and minimize resource degradation. However, supporting the operational costs of long-term monitoring can be challenging or prohibitive. This paper addresses a core issue related to the efficiency of trail condition IA&M efforts: reducing the number of measurements needed to characterize aggregate soil loss across a trail network. Specifically, the number of measures required to estimate the cross sectional area (CSA) of soil loss at sampling locations along trails was examined by fitting data from five protected area trail networks to known geometric reference curves. The reference curve formulae were calibrated to the data using empirically derived coefficients, then were tested against additional field data for accuracy. Results indicate that geometric figure approximation can be used to determine soil loss with a high degree of accuracy and reduced field effort. These findings suggest that simplification of common recreation ecology field protocols using relationships described by reference curves can markedly reduce the field data collection time required for estimating aggregate trail soil loss. This technique provides a substantially more efficient option in comparison to current field-based IA&M protocols, allowing for the collection of aggregate trail soil loss estimates or improves the efficiency of programs that already include such estimates.

Author keywords: trail impact monitoring, erosion, cross sectional area, soil loss, modeling

Managing Indicators and Standards

Since their inception, U.S. federal land management agencies have been tasked with the stewardship of their natural resources into perpetuity. The interpretation of "stewardship" takes as many forms as there are agencies. However, preventing or minimizing recreation-associated resource impacts play a role in how all parks, forests, recreation areas, wilderness, and other protected areas (hereafter, "parks") are managed. For example, the U.S. National Park Service (NPS) is charged with the "preservation" of resources "unimpaired for the enjoyment of future generations" (National Park Service Organic Act §1, 1916). This legislative mandate, however, is challenging to implement. Any level of natural resource-based recreation brings associated changes, some negative (i.e., "impacts"), to the resource (Hammitt and Cole 1998). Consequently, management of impacts persists as a key interest to land management agencies, particularly in light of strong, continuing participant interest in various forms of outdoor recreation (Cordell and Super 2000).

To address this need, parks have adopted planning and decision-making frameworks that provide similar structured processes for addressing the potential impacts of recreation, including: Limits of Acceptable Change (Stankey et al. 1985), Visitor Impact Management (Graefe et al. 1990), Protected Area Visitor Impact Management (Farrell and Marion 2002) and Visitor Experience and Resource Protection ("VERP") (Manning et al. 1999, NPS 1997). The VERP framework adopted by the NPS, for example, involves setting broad, narrative management goals that reflect the recreation values attached to the resource (Manning 1999). These broad goals are translated into numerous management objectives, specific and narrow in scope, often addressing social or resource conditions in a spatially defined physiographic setting or management zone. A typical objective might be "to reduce and prevent soil loss resulting from recreation along natural surface trails." These objectives are formulated such that they can be evaluated with individual indicator variables.

Indicators are quantitative; sensitive to real changes in conditions; and efficient, repeatable, and inexpensively measured values that accurately reflect success in achieving management objectives (Manning 2003). Examples of trail condition indicators include trail width, depth (incision), soil loss, muddiness, and informal trail proliferation (Hammitt and Cole 1997). For each *descriptive* indicator, a *prescriptive* standard is set as an impact acceptability limit on the range of values that an indicator may exhibit within a management zone. For example, trail widths may range up to a maximum of 3.5 feet in a park's Natural Zone. Periodic monitoring evaluates current resource conditions in light of established indicator standards. If standards are demonstrably exceeded, appropriate management interventions are undertaken to rectify the problems (Manning 1999).

Monitoring is a key aspect of VERP's effectiveness, providing periodic reports to managers on social or resource conditions for comparison to standards (Newsome et al. 2002). Monitoring data can be analyzed to characterize trends in conditions or provide insights on the factors driving or influencing changes in conditions (Farrell and Marion 2002). However, the long-term cost of monitoring can be burdensome, requiring staffing, sustained assessments and analyses amidst institutional turnover, and uninterrupted funding. VERP monitoring procedures are intended for indefinite use; managers must be committed to sustaining the necessary operational costs in perpetuity.

This study is an effort to address this challenge -- the expense and time required for monitoring -- for several important and commonly used physical indicators of trail condition: trail tread cross sectional area (CSA), width, maximum incision (MAX, deepest point in the tread at a sampling location), and modal incision (MOD, the most common tread depth at a given sampling location). The periodic collection of these data is time- and labor-intensive, requiring trained field staff to both take and analyze considerable amounts of data for extensive trail networks. With increased assessment and analytical efficiencies, managers could more easily accommodate and sustain trail resource monitoring and meet legislative mandates to preserve or conserve trail resources.

Efficient Data Collection

Many studies have explored the causal factors of trail soil loss (Table 1). Several of these studies and others characterize localized soil loss by deriving CSA from a series of measures taken at sample points along trails (e.g., Helgath 1975, Burde and Renfro 1986, Fish et al. 1981). CSA as a point sampling technique was first developed by Leonard and Whitney (1977) as a technique for characterizing soil loss for low n, non-representative trail condition surveys (Cole 1983). Later work clarified the value measured by CSA as a combination of soil erosion, compaction, and displacement (collectively, "soil loss") and expanded the technique across entire trail systems (Godwin 2000, Wimpey and Marion, in press). The procedure requires field staff to measure trail width at the sampling location (Figure 2-1, see also Appendix I) by planting metal stakes at both edges of the trail, affixing a measuring tape between the stakes, and recording a series of carefully-collected incision (i.e., depth) measures at fixed or variable intervals across the tape down to the actual tread surface below. Wider trails require additional 1) incision measures 2) time to input data values in the field and 3) time to calculate square area from the width and incision measures.

This CSA procedure provides an accurate and detailed measure of soil loss at the sampling location, a useful indicator of resource degradation when applied across an entire park. However, the number of measures required at each sampling point and the number of sampling points required to accurately characterize a trail network can easily grow to be cost-prohibitive when considered as a periodic monitoring effort. As a result, many studies have only applied this method at a small, non-representative collection of sample locations or permanent transects (e.g., Fish et al. 1981). More recently, several studies have examined the utility of spatially representative sampling of CSA and related measures (e.g., Leung and Marion 1999a). This approach removes the need to revisit fixed sample points determined by physical datum markers. This representative approach, while able to equip managers with an accurate understanding of soil loss along a trail system, typically requires hundreds of sample points and protracted fieldwork. Hammitt and Cole (1998) recommend a hundred sample points for each "situation of concern" and twice that for comparative studies. It seems clear that CSA collection is currently an effort-intensive process. One way of reducing the labor associated with CSA measures would be development of a CSA model that accurately generalizes individual CSA profiles into an aggregate. However, models of the characteristic shapes of these CSAs have not been investigated in the recreation literature to date, nor have procedures for substantially simplifying soil loss measurements and estimates based on the CSA method. For example, if CSA profiles are relatively homogeneous, it should be possible to mathematically model their shape and take fewer measurements yet produce accurate estimates of soil loss at trail transects. This research paper examines the following research questions: 1) does a generalized geometric relationship exist that describes CSA profile shape, and 2) can that shape be meaningfully approximated with simplifying geometric primitives?

Background

Human presence in the outdoors affects many aspects of the natural world in subtle and overt ways. The field of recreation ecology investigates the range of resource changes associated with visitor use to protected natural areas, including vegetation, soils, water resources, and wildlife (Leung and Marion 2000, Hammitt and Cole 1998, Cole and Wright 2003). These changes can be positive or negative with respect to the health, integrity, and function of natural resources. Some subset of these changes may be considered negative, or "impacts," such as soil loss (Bayfield 1986), lowered wildlife breeding success (Lord et al. 2001), or the introduction of exotic invasive species (Benninger-Truax 1992, Tyser and Worley 1992). Some impacts are considered unavoidable (e.g., soil transport during trail construction), and therefore deemed acceptable or even "positive" changes (Bircher and Proudman 2000). In all cases, however, managers must seek to minimize unavoidable and avoidable impacts to the greatest extent possible (Watson et al. 2000).

These impacts are linked to each other in dynamic and complex webs of interaction. Manning (1979) frames a typical series of soil and vegetation impacts as a positive feedback cycle. Footfalls (or wheels) weaken then remove vegetation, and pulverize organic matter overlaying and protecting the trail tread substrates (Whinam and Chilcott 2003). The pulverized matter is then more easily blown or washed away (soil profile truncation), exposing the underlying mineral soil to compaction and soil loss via subsequent footfalls, precipitation events, or wind (Marion and Merriam 1985). Most soils, excluding bedrock or rocky soils, cannot long withstand the ground pressure of 10 – 40 lbs/sq. in. generated by various kinds of foot and hoofed traffic (Hammitt and Cole 1998, Kuss Graefe and Vaske 1990, Liddle 1997).

Once compacted, the upper horizons of mineral soil lose porosity; water infiltration rates drop and overland flow increases both in volume and velocity. In addition, the combined compaction and soil loss, left unchecked, cause treads to become depressed or incised relative to trail sides. Incised treads channelize water flow along the trail and magnify the transport (erosion) of pulverized organic matter and tread substrates. This process occurs to varying degrees on nearly all natural surface foot trails with rates influenced by trail grade, substrate type, trail slope alignment angle, and the presence and efficacy of tread drainage features (Hammitt and Cole 1998; Leung and Marion 1996; Olive and Marion 2007). The loss of soil on recreational trails is a serious long-term impact for park managers because it is self-reinforcing, alters local hydrology through sediment and pathogen transport, nutrient-loading waterways, altering aquatic habitat, and can be expensive to mitigate.

Given the impacts and costs involved, park managers often desire to monitor the condition of their trail systems to become aware of problem areas before deterioration reaches unacceptable levels. Marion and Leung (2001) describe and compare two alternative trail monitoring methods, each providing distinct kinds of data, and commonly applied to achieving trail monitoring objectives.

The problem assessment method involves assessing a predefined set of trail condition problems continuously to document all segments of trail exhibiting one or more problems. This method is most useful for providing information on a limited, predefined set of infrequently occurring problems, such as muddy stretches of trail (Leung and Marion 1999b). In contrast, a point sampling method derives a statistically representative characterization of tread conditions for surveyed trails through assessments at sample points spaced a fixed distance along trails beginning with a random start. Conditions at the sample points are extrapolated to characterize the trail's or trail network's condition. The point sampling approach is most useful for understanding continuous (e.g., width and depth) and/or frequently occurring trail conditions.

These trail condition assessment methods are similar in assessment times and can be combined for an integrated survey (Leung and Marion 1999b). The problem assessment method is most efficient when trails are in good condition, while the point sampling approach requires frequent measurements that can be time-consuming depending on the number of indicators included and how they are assessed (e.g., width and incision measurements) (Marion et al. 2006). As a result, cost and staffing limitations can prevent use of this highly informative quantitative technique (Marion and Leung 2001).

A common indicator of soil loss assessed in point sampling surveys is cross sectional area (CSA) (Leonard and Whitney 1977, Coleman 1977, Rinehart et al. 1978). It requires the periodic collection of tread width and multiple measures of tread depth, or incision (Figure 2-1) to construct a geometric representation of soil loss due to compaction, displacement, and erosion. Tread depth measures are taken from a line stretched between tread boundary points and configured to represent the post-construction tread surface. Earlier applications of the CSA assessments applied this method only at permanent sampling points, with replications over time to document soil loss only at those points. Marion and Leung (1999b) adapted this method to representative point sampling surveys to provide mean and aggregate estimates of soil loss for entire trails or trail networks.

Pappus' theorem, that the volume of an extruded plane figure (i.e., a CSA polygon) is the area of the figure times the length traveled by the polygon's centroid along the extrusion path (i.e., the interval distance between sampling points) is useful in this application (Aruga 2005). A related approach, the prismoidal method ("average end area" method), averages the two end areas (i.e., CSA profiles) and multiply by distance to calculate tread soil loss volume, in effect interpolating one cross section profile into the next along the distance of the segment or interval.

While CSA measurements at each sampling point require only several minutes to assess, multiplied across a trail network of a hundred or more lineal miles, the time required to assess this single indicator can be a significant deterrent to efficient data collection. Industrial forestry and channel hydrology literature, however, provide some useful insights for making this procedure more efficient, albeit at much larger spatial scales. Forest road construction generates many problems analogous to those of trail development and monitoring (albeit on a larger spatial scale), such as erosion and sediment transport into streams (Lane and Sheridan 2002). Aruga et al. (2005) describe a simple geometric method for approximating the CSA of soil to be excavated for cut and fill operations during logging road construction (Figure 2-2). A similar approach has been used to estimate stream channel cross sections (Ames et al. 2008, Bhatt and Tiwari 2008). Broken down into ordinary polygons, complex cross section measurements can be abstracted accurately and quickly in the field.

Therefore, the goal of this study is to determine potential hypothetical geometric figure abstractions for aggregate CSAs (Figure 2-3) and to test their efficacy in predicting CSAs against actual field data from several physiographic regions of the United States. Successful geometric figure approximation would enable managers to reduce the workload of monitoring field staff by reducing the number of measurements needed, limiting monitoring costs over time. The procedure would require width and numerous incision measurements for only the initial round of resource monitoring. Subsequent monitoring would rely on empirical geometric relationships derived from the initial dataset to determine CSA from only two measures: trail width and MAX.

Methods

To determine the effectiveness of using geometric figures to approximate CSA change, trail data were collected from a diversity of park settings. Six protected areas were representatively sampled for this study. Five areas were used to calibrate CSA approximation models: Acadia, Zion, and Haleakala National Parks, and the Potomac Gorge sections of the George Washington Memorial Parkway and the C & O Canal National Historic Park. A sixth area, Big South Fork National River and Recreation Area was sampled to provide a validation dataset (Table 2). Due to the size of each study area and topographic variation, it is difficult to assign a single soil series.

Sample locations at each study area were located using a measuring wheel or GPS device and each study employed a fixed sampling interval (e.g., 300 ft) with a random start (Marion and Hockett 2008a, Marion in press, Marion, Wimpey and Park in press, Marion and Hockett 2008b, Marion and Carr 2009, Marion and Olive 2006). The measuring wheels were used to locate systematic random-sampled points based on traversed distance; the GPS units were used to locate systematic random-sampled points based on algorithmic point placement in a GIS environment. Both techniques produce an equivalently random sample. In the case of GPS-based collection at Acadia National Park, sample points were selected using ARCMap 9.2 GIS and an ESRI "points along polys" algorithm macro script applied to the park's trail layer. Intervals between sampling points were consequently more variable and a Trimble GeoXT and Hurricane antenna was used to locate sample points.

At each sample point, data were collected using one of two parallel approaches for CSA determination, fixed and variable interval measurements (Table 2). Removable stakes were inserted into the soil marking the outer boundaries of the trail surface. A measuring tape or line was strung taut between the stakes and fixed into place to approximate the original soil surface or the post-construction tread surface for fall line (i.e., direct ascent) trails or sidehill trails respectively (Figure 2-1). In places where substantial older "historic" soil loss had occurred, field staff assessed soil loss only within the context of the current, active tread (Farrell and Marion 2002). CSA was assessed by recording tread width and multiple vertical incision measurements from the tape or line down to the tread surface. For fixed interval study areas, these incision measures were taken at fixed periodic lengths along the line, generally at 0.3 or 1.0

foot intervals, depending on tread width. For study areas assessed under variable interval methods, incision measures were located along the line according to field staff characterization of the tread rugosity at the sampling location (Manning, Jacobi, and Marion 2006) (Figure 2-1). CSA was not assessed for sampling locations with artificial substrates (e.g., boardwalk or puncheon bridging) or bedrock.

Data were entered into Microsoft Excel spreadsheets and examined for data entry errors. CSA profiles were constructed for each sample location across the five study areas. To standardize data across fixed and variable interval collection techniques, data for each sampling location were normalized to 100% percentage width. Each CSA curve was processed in Excel for linear interpolation of soil incision depth between sample points along the curve. The sample profile depths were resampled at arbitrarily small 0.1% width intervals (1001 interpolated incisions per curve; e.g., 6 inches incision at 4% of width, 6.25 inches at 4.1% of width, etc.).

A typical CSA profile is not symmetrical with respect to direction of measurement due to sideslope and water drainage design effects (e.g., treads are often outsloped 3-5% to efficiently drain water). Profiles were therefore symmetry-corrected by splitting each normalized profile at its width's center point, creating two curves for each sampling location, then averaging these together by corresponding incisions to provide data sets corrected for field staff's direction of field travel (Figure 2-4). Finally, the normalized and symmetry-corrected profiles for each research site were aggregated for visual inspection of appropriate reference curve selection and to provide an "average" or generalized CSA profile for each research site (Figure 2-5).

The normalized, symmetry-corrected profiles were compared against families of reference profiles based on simple geometric figures, including rectangles, regular right trapezoids, ellipses, and second order polynomial parabolas. Sample point width and MAX (deepest recorded incision in trail surface at sampling point) were mapped to width and height values of the reference profiles (e.g., for a semi-elliptical reference profile, the semi-major axis corresponded to tread width and the half-semi-minor axis corresponded to MAX. Best-fit scaling coefficient parameters were determined empirically for each sample location across all study areas by scaling MAX by increments of 1.0% from 1% to 200%. The goodness of fit for each scalar value of MAX was calculated as root mean square error (RMSE) for predicted interpolated incision values versus empirical results for each interpolated incision. The scaling coefficient resulting in the smallest RMSE was selected as the optimal value for that point. Central tendency values across all scaling coefficients for each study area were calculated as the summary statistic of best fit. This procedure was repeated for fourth order polynomial curve fitting.

Model Development

The averaged CSA profiles varied considerably between study areas (Figure 2-5). The profile describing Haleakala National Park's trail network was comparatively angular and irregular, possibly driven by the unconsolidated loose volcanic cinder substrate. Among the four study areas' aggregate profiles, it was the most similar to that of a stream channel with a deeper center "channel" (analogous to a thalweg in fluvial geomorphology) and flatter shoulder areas. The profiles for ACAD and ZION were substantially more curvilinear, most likely due to finer textures and the soil accretion effect of higher organic material content.

The CSA profiles, aggregated by park, were fitted against various reference profiles based on geometric primitives. Three families of primitives were assessed: rectilinear, curvilinear, and parabolic. The rectilinear family of reference profiles included rectangular, trapezoidal, and triangular profile approximations, based on typical CSA profiles observed in the field. From a mathematical perspective, however, analysis of rectilinear profiles beyond a rectangular profile yields no additional information (e.g., the formulae for areas of a rectangle and trapezoid are functionally equivalent). Fitting a rectangular model to the CSA profile data represents the assumption that a regression line connecting incision depths does not explain incisions (i.e., the average of incisions across all widths is the correct predictor). Zion National Park tended to have the shallowest incisions overall, resulting in a mean MAX best-fit scaling factor of 0.57 (Table 3). This result is partially due to a large minority of sample points being located on bedrock substrates i.e., where CSA is functionally zero. The remaining three study areas were more similar. The empirical best-fit MAX scaling factor for Potomac Gorge was 0.63 and 0.66 for Acadia and Haleakala. In analytic geometry terms, this scaling factor suggests that the expected CSA for a given point along a trail in these three parks is about two-thirds the area of a rectangle circumscribed around the CSA profile.

Fitting the CSA profile data to a semi-elliptical model produced similar relationships among the data. The average MAX scaling factor for profiles at Zion was 0.73, again lower than the scaling factor for the other study areas (Table 3). Mean scaling coefficients for Acadia, Haleakala, and Potomac Gorge were between 0.84 and 0.88. The comparatively higher coefficients for the semi-elliptical geometric model confirm that the curvilinear approach is a closer fit to aggregate profiles than a rectangular method for CSA profiles in the study areas involved. However, the non-unity value of the best-fit coefficients indicates that the elliptical approach is not suitably accurate for trail system-wide use.

Aggregate CSA profiles were also fitted to second order (quadratic) polynomial reference curves i.e., parabolas. Goodness of fit was calculated for the profiles as R^2. The aggregate profile for Acadia's trail system was regressed in this manner with an R^2 value of 0.9909; for Zion R^2 is approximately 0.999 (Table 4). Other aggregate profiles were also strongly parabolic in nature; the least well-fit profile corresponding to the POGO study area returned an R^2 value of 0.9376. This result suggests that polynomial approximation of CSA profiles is the most effective among rectilinear, curvilinear, and polynomial estimations of CSA. Subsequent derivation of area under a parabolic polynomial is based on Rozen and Sofo's (1985) proof that the chord running between the endpoints on the parabola encloses an area equal to 2/3rd the area of the circumscribing parallelogram. With symmetry correction performed on the aggregate profiles, this chord is constrained to perpendicularity to the axis of the parabola, constraining the circumscribing parallelogram to a rectangle and confirming the empirical rectangular MAX scaling factor of 0.66 described above.

A refinement on the parabola fitting approach was use of fourth order (quartic) polynomial fitting. Addition of the higher order fitting parameters improved R^2 values over quadratic fitting in all cases (Table 5). For the Zion data set, R^2 improved from 0.9990 to 0.9997. The data set worst-fit by the quadratic approach, Potomac Gorge, improved R^2 from 0.9376 to 0.9982 by adopting a quartic fit. This quartic curve fitting approach was the most accurate among the four CSA approximation types tested. Subsequently, CSA would be estimated for a given sample point by calculating the definite integral of the function described by the fitting coefficients and measured sample point width.

Model Validation

To validate these CSA approximation methods based on the four study areas involved, CSA profile prediction was performed on a separate, fifth CSA dataset representing the trail system of Big South Fork NRRA. Rectangular and semi-elliptic approximations of aggregate CS profile placed this study area at the low end among profiles in terms of scaling factors (0.56 and 0.73 MAX scaling factors respectively) (Table 3). Consequently, using the lowest values provided from the models built for the four source study areas yielded the most accurate estimations of CSA (Table 6). For this reason, the 2^{nd} order polynomial model, corresponding to a rectangular model scaled at the high end of the empirical coefficients, was a poor predictor of pointwise and aggregate CSA (14.1% error). The lowest of the four developed elliptical MAX scaling factors, 0.73, closely approximated Big South Fork's endogenous MAX scaling factor for the validation dataset and resulted in the prediction with the lowest percentage error, 0.17%.

Using an evenly weighted average of MAX scaling coefficients across all parks, 0.616, and a rectangular approximation, the model predicts CSA with 7.08% error. This approach is a first step toward development of a generalized set of coefficients usable across trail network locations though additional datasets are needed to further calibrate the generalized case. A polynomial model constructed for the same purpose would provide a more accurate estimate at the cost of slightly more complex calculations. However, spreadsheets or other software can be configured to handle the required calculations automatically

These results underscore the importance of developing MAX scaling factors endogenously when using a rectilinear or curvilinear predictor model of CSA. It should be noted, however, that for a representative initial sample involving detailed CSA measures, the resulting endogenous model always will be the most accurate set of predictor variables for CSA approximation, regardless of the geometric figure used.

Conclusions

This geometric figure technique can be used to approximate soil loss through CSA estimation with a high degree of accuracy in some cases. However, this approach is not appropriate for answering certain questions about trail systems' physical conditions (e.g., problem assessment identification of soil loss hotspots). Soil loss along trails is highly variable within a single park by up to an order of magnitude (Bratton et al. 1979). However, a park-wide

CSA estimation approach efficiently abstracts these differences to determine overall conditions or condition by zone.

It should be noted that relying on mathematical generalization of trail profiles does not--like any stochastic model—provide reliable results for small n situations (e.g., attempting to characterize a single trail with a few CSA sampling points). In these low n cases, it is probably more useful for practitioners to collect the more detailed CSA measures without addressing mathematical relationships among profiles. How large of a sample is large enough? Samples that produce visibly irregular aggregate profiles should be increased in size. Averaging aggregate incisions through symmetry correction effectively doubles sample size, but care should be taken to avoid relying on this correction as a crutch. For larger trail systems, though, where n is sufficient to produce a regular, smooth profile, abstraction can provide material savings in effort.

This abstraction shifts the burden of labor from expensive data collection effort in the field (by reducing the number of measurements needed) to ordinary data processing effort in the office. The cost of deploying field staff for occasional monitoring efforts (e.g., every 5 years) can be a periodic, high sum that should be reduced wherever possible while sacrificing minimal accuracy. Managers would need to run the labor-intensive full characterization of CSA across the trail network only once with this approximation approach to determine or verify the appropriate geometric figure and coefficients needed. Subsequent efforts on the given trail network would require only width and MAX measures to provide equivalent data. The necessary values and calculations can be automated in spreadsheet software after they have been ascertained in the initial effort.

In larger trail networks that are highly heterogeneous with respect to trail environments, it would be useful to zone internally homogeneous sub-networks or zones as a variance reduction technique. This technique is analogous to spatially stratifying the data. For example, at Haleakala National Park, dramatic qualitative differences exist in the general CS profiles for trails atop loose cinder on the dry side of the park's high altitude volcanic crater, the organic material-rich wetter side of the crater, and the wet seaside Kipahulu trails area. However, there is a strong need for more research to better understand the determining factors of CS profile shape. The almost perfectly parabolic shape of most of the profiles studied here suggest strong relationships between use and physical tread characteristics, however little trails-based relational analyses have to date examined this problem (e.g., Godwin 2000). Why are some profiles more angular than others? It should be noted however that these aggregate profiles are more alike than they are dissimilar. This regularity of aggregate curves for each research site confirms the face validity of using the geometric approximation approach. In addition, development of a generalized geometric figure approach is possible as a first-order approximation method.

Use of a quartic curve to fit a protected area's aggregate CSA profile provides a high degree of curve fidelity. However, it may be more realistic for practitioners to adopt the quadratic approach's simpler calculations to avoid the integration and constant-value solving needed to use quartic CSA approximation. In addition, the improvement of R^2 realized by moving from a quadratic to a quartic solution is minimal relative to the inherent uncertainty in all stochastic models.

Similarly, some fitted curve coefficients (Table 2-4) have vanishingly small values—many orders of magnitude smaller than the variance of the associated dataset. For example, the B term for Acadia National Park's trail system is -1.93×10^{-16}. These coefficients may be safely dropped from the fitting equations, as they could otherwise communicate a degree of mathematical precision that is not reflective of reality.

Monitoring is an expensive proposition for protected area managers. The research community can assist managers in maximizing monitoring efficiency by developing accurate methods that reduce inventorying and monitoring time and costs. Within the context of trail soil loss monitoring, practitioners can exploit the strengths of collecting a representative set of point samples across the entire trail network. This enables mathematical approximation methods based on geometric figure approximation, reducing the number of measurements needed to characterize soil loss. While substantial initial effort is required to establish the aggregated profile for the study area, subsequent efforts are much less field-intensive. Likewise, office calculations can be standardized in spreadsheet software. The averaged profile created during this process is a useful snapshot reference of aggregate tread condition and a benchmark for future measurements.

The CSA geometric figure approximation method suggests areas for further research inquiry. An alternate approach to fitting a geometric figure to profiles would be to build a distribution of depths at any given percent width. Using those distributions, predictors of CSA can be derived. However, no research effort has examined this application in the context of hiking trails. In addition, not enough is known regarding the factors governing why some profiles adopt different shapes, and how these shapes may evolve over time.

Tables

Table 2-1. Factors driving soil loss along trails.

Study	Slope	Substrate /Texture	Vegetation Type	Elevation	Precipitation	Use Type/ Amount	Soil Moisture	Landform	Shade	Surface Treatment
Bjorkman 1998	+		+						+	+
Bratton et al.1979	+		+	+						
Bryan 1977		+/-								
Burde and Renfro 1986	+	+/-	+	+	+	+				
Cassios 1987	+	+								
Clark 1994	+	+						+		
De Luca 1998	+				+	+/-				
Godwin 2000	+		+/-				+			
Helgath 1975	+	-	+	-		-		+		
Kuss 1986						-				
Summer 1986								+		
Urie 1994	+		-				+			
Whittaker and Bratton 1980	+						+			
Yoda and Watanabe 2000	+		+				+			

Table 2-2. Research site soil type and substrate, CSA method, and location.

Research Site	Soil Type & Substrate	CSA Method	Location
Acadia National Park	Coarse-loamy, mixed, frigid, Aquic Haplorthods and glaciomarine till over k-spar granite and Ellsworth schist formations[1,2] (spodosols)	Fixed, variable interval	Coastal Maine
Haleakala National Park	Hanipoe and Apakuie series over volcanic basalt[3] (andisols)	Fixed interval	Coastal and volcanic montane Hawai'i
Zion National Park	e.g., Bond, Mathis Rock outcrop complex, Redbank fine sandy loam[4] (lithic aridisols)	Variable interval	Southwestern Utah
Potomac Gorge	Captina, Wehadkee, Glenville, Chewacla, Manor, Glenelg, Meadowville, and Elioak series[5] (ultisols, varied)	Fixed interval	Coastal Virginia, Maryland
Big South Fork NRRA	Jefferson, Shelocta, Muse and Cranston series over sandstone or siltstone[6] (ultisols, alfisols)	Variable interval	Central southern Kentucky, north central Tennessee

1 - MDOT 2006, 2 - Parker et al. 2001, 3 - Smith and Cuddihy 1984, 4 - NRCS 2009, 5 - NPS 2007, 6 - Martin 2003.

Table 2-3. Geometric figure curve fitting coefficients and regressions.

Geometric Model (Scaling Parameter)	Research Site	Mean Best-Fit MAX Scaling Factor	Median Best-Fit MAX Scaling Factor	n	St Dev
Rectangular (MAX)	Acadia National Park	0.66	0.68	632	0.16
	Haleakala National Park	0.66	0.63	178	0.27
	Potomac Gorge	0.63	0.64	151	0.22
	Zion National Park	0.57	0.58	197	0.08
	Big South Fork	0.56	0.56	372	0.10
Elliptical (MAX)	Acadia National Park	0.88	0.89	632	0.20
	Haleakala National Park	0.84	0.81	177	0.26
	Potomac Gorge	0.87	0.89	150	0.24
	Zion National Park	0.73	0.75	202	0.10
	Big South Fork	0.73	0.73	372	0.13

Table 2-4. Second order (quadratic) polynomial curve fitting parameters by study area.

Research Site	A Coefficient	B Coefficient	C Constant	n	R^2
Acadia National Park	-4.93x10-4	-1.93x10-16	2.35	1001	0.9908
Haleakala National Park	-0.0013	-1.65x10-17	4.19	1001	0.9704
Potomac Gorge	-2.07x10-4	-6.72x10-18	1.27	1001	0.9376
Zion National Park	-6.87x10-4	4.08x10-17	1.75	1001	0.9990
Big South Fork	-0.0012	$-1.0x10^{-16}$	0.4278	1001	0.9634
Aggregated (even weight)	-7.80x10-4	1.99x10-16	2.61	1001	0.9799

Note: coefficients and intercept correspond to the standard second order polynomial equation fitted for incision depth at percentage width i, $v_i = Aw_i^2 + Bw_i + C$

Table 2-5. Fourth order (quartic) polynomial curve fitting parameters by study area.

Research Site	D Coefficient	E Coefficient	F Coefficient	G Coefficient	H Constant	n	R^2
Acadia National Park	$-6.98x10^{-8}$	$-4.74x10^{-18}$	$-3.44x10^{-4}$	$3.20x10^{-15}$	2.31	1001	0.9990
Haleakala National Park	$-2.82 x 10^{-7}$	$-1.60x10^{-17}$	$-6.91x10^{-4}$	$1.84x10^{-14}$	4.04	1001	0.9893
Potomac Gorge	$-8.22x10^{-8}$	$-4.47x10^{-18}$	$-3.05x10^{-5}$	$4.49x10^{-15}$	1.22	1001	0.9982
Zion National Park	$-2.74x10^{-8}$	$-4.53x10^{-19}$	$-6.28x10^{-4}$	$-7.53x10^{-15}$	1.74	1001	0.9997
Big South Fork	$-3.7x10^{-7}$	$-2.28x10^{-17}$	$-4.29x10^{-4}$	$3.01x10^{-14}$	3.29	1001	0.9995
Aggregated (even weight)	$-1.67x10^{-7}$	$-1.31x10^{-17}$	$-4.23x10^{-4}$	$5.97x10^{-15}$	2.52	1001	0.9982

Note: coefficients and intercept correspond to the standard fourth order polynomial equation fitted for incision depth at percentage width j, $v_j = Dw_j^4 + Ew_j^3 + Fw_j^2 + Gw_j + H$

Table 2-6. Model validation utilizing Big South Fork data.

Models	Scaling Coefficient	Mean Pointwise Percentage Error	CSA Prediction Percentage Error
High end rectangular	0.66	14.6	13.27
Low end rectangular	0.57	1.1	-0.41
Endogenous rectangular	0.56	-0.6	-2.23
High end elliptical	0.88	18.5	17.18
Low end elliptical	0.73	1.7	0.17
Endogenous elliptical	0.73	1.7	0.17
2^{nd} order polynomial	--	15.5	14.14

Figures

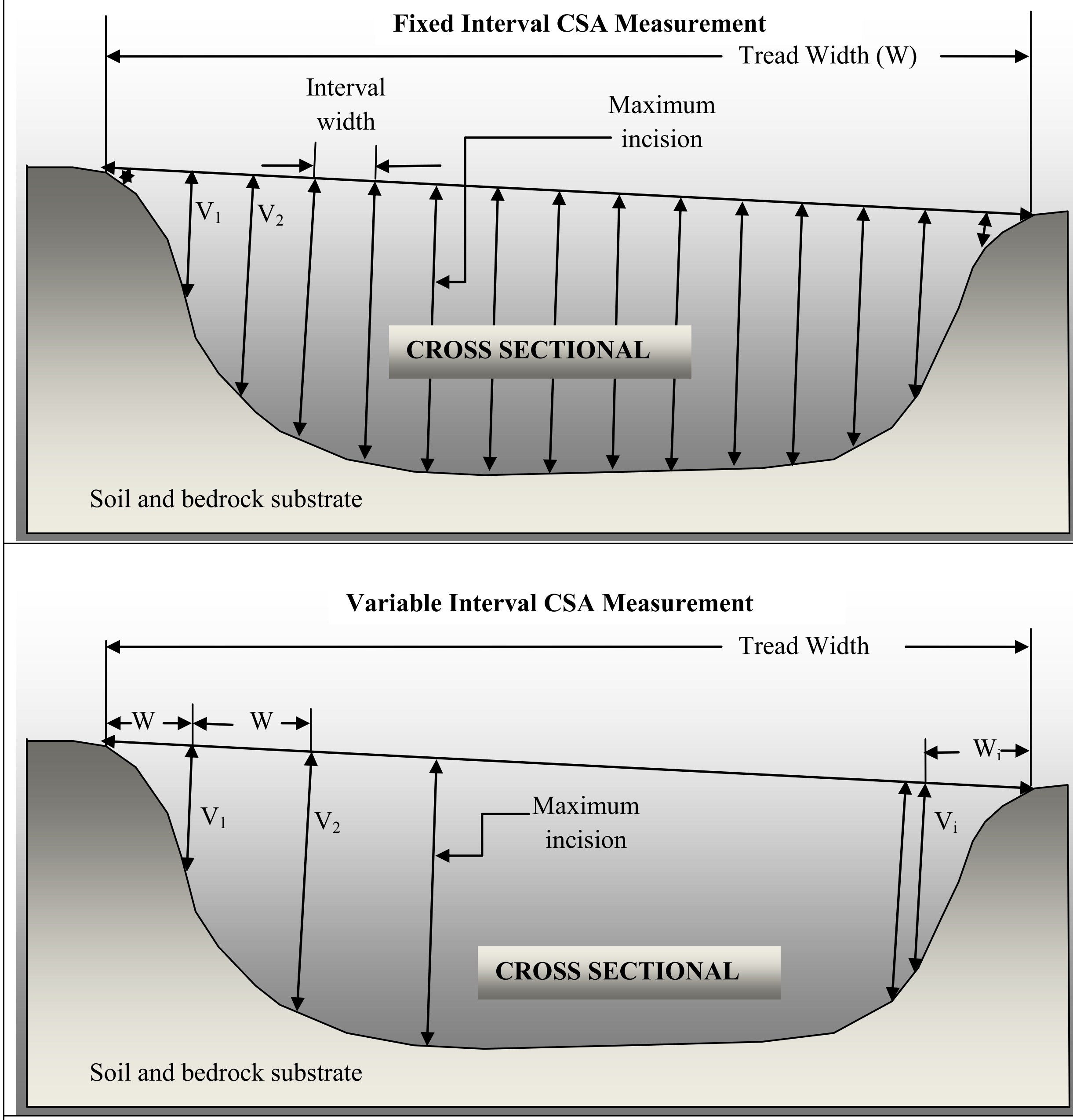

Figure 2-1. General diagrams of fixed and variable interval CSA measurement components. Adapted from Marion 1994.

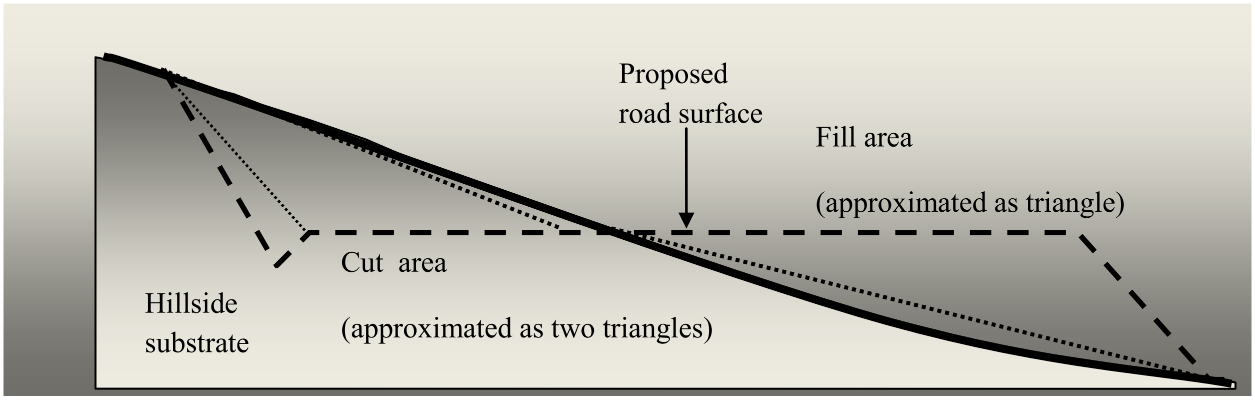

Figure 2-2. Geometric method of CSA approximation for cut and fill equalization planning on logging roads . Adapted from Aruga et al. 2005.

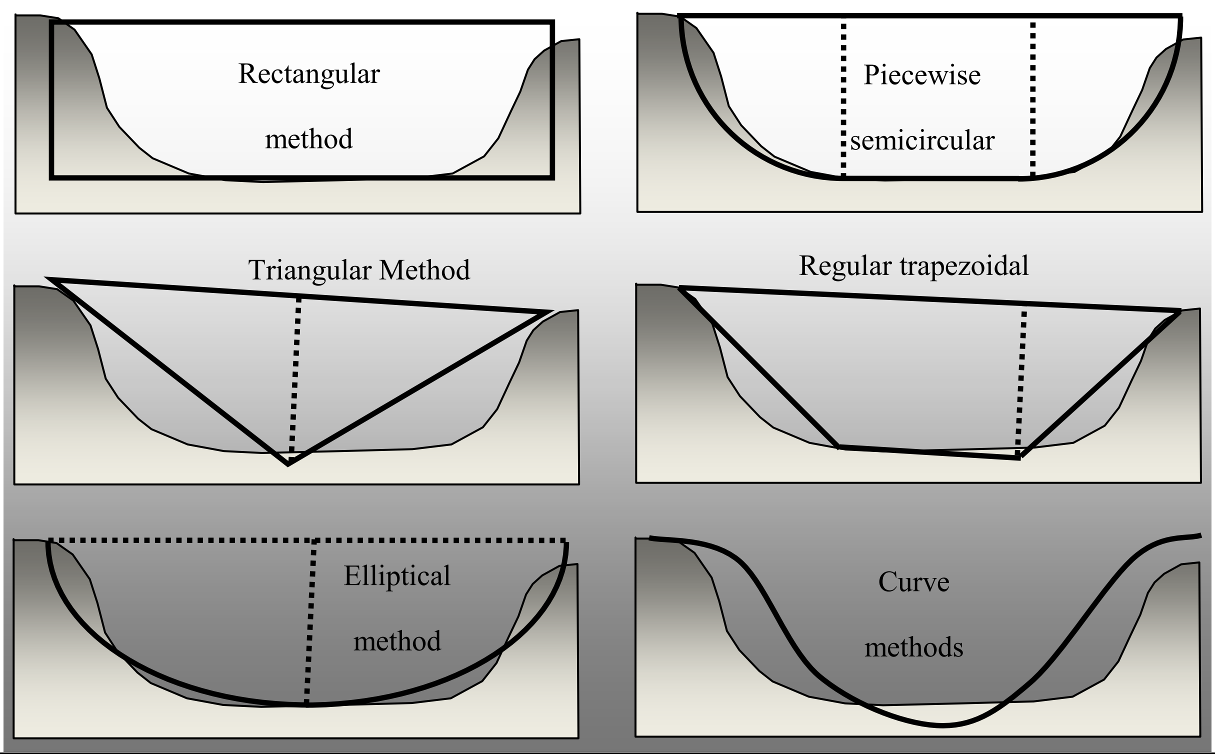

Figure 2-3. Example hypothetical geometric curves usable in approximating CSA using fewer measurements than traditional means.

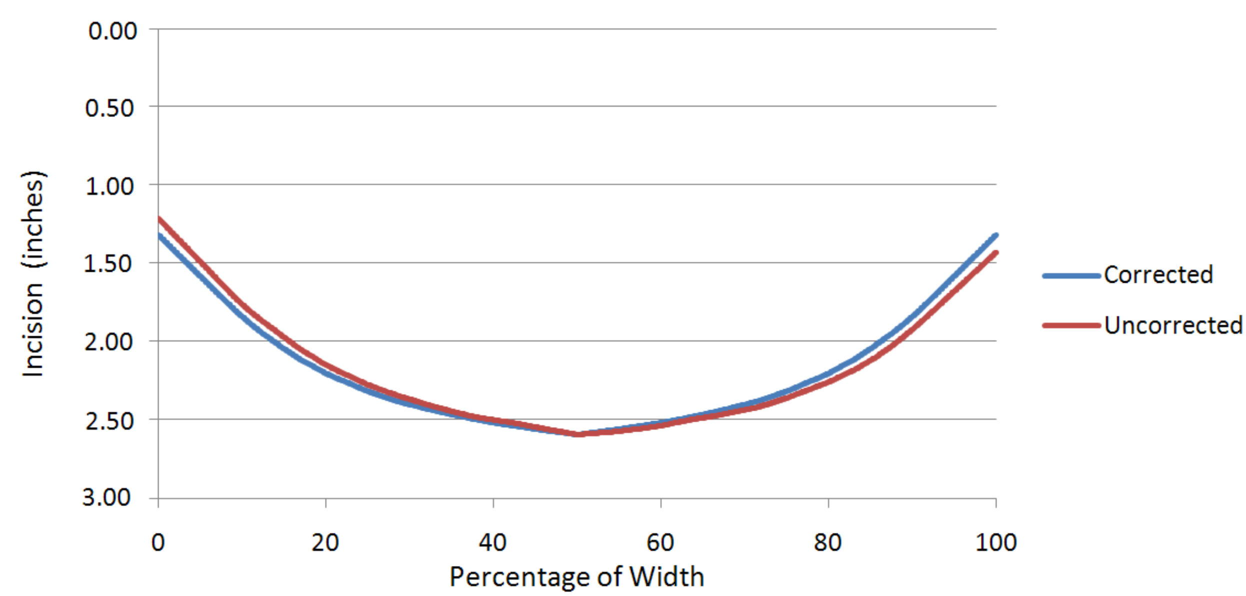

Figure 2-4. Aggregate percentage width-normalized CSA profile for Acadia National Park Trail system, pre- and post-symmetry correction.

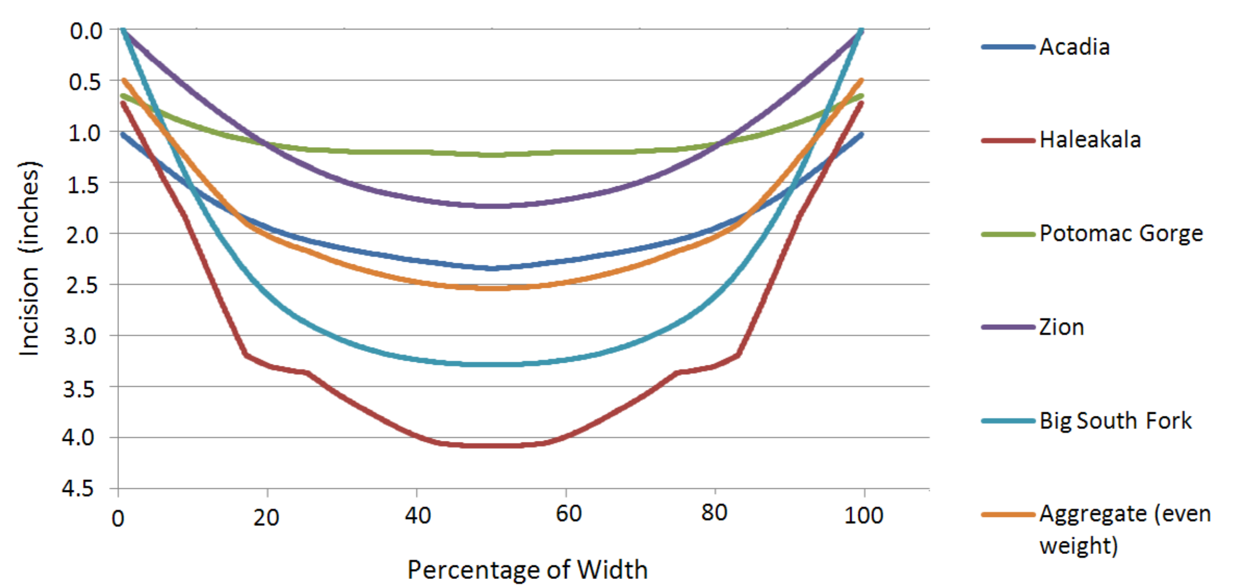

Figure 2-5. Aggregate percentage width-normalized, symmetry-corrected CSA profiles by study area and overall.

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Application of Sound and Spatial Modeling to Visitor Experience Management at Rocky Mountain National Park

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ABSTRACT

Natural and cultural sounds are integral components of the suite of resources and values that the NPS is charged with preserving, restoring, and interpreting (Director's Order 47, 2000). Anthropogenic noise (e.g., transportation sounds), however, can obfuscate natural and cultural sounds as well as having negative ecological effects (e.g., Burger and Gochfeld 1998, Martin 1999). Soundscape-related indicators and standards of quality are now being developed at a number of national parks, but measurement of some indicators, including soundscape metrics which vary greatly spatially and temporally, is nontrivial (Lawson and Plotkin, 2006; Ambrose and Burson, 2004). This paper describes a spatial modeling project designed to quantify the effects of alterations to shuttle bus transportation amenities on hiker soundscapes at Rocky Mountain National Park. Indicator variables were calculated including percentage of trip spent in natural quiet, distance hiked to reach natural quiet, and the percentage of visitors experiencing at least 15 minutes of natural quiet. Results illustrate that small changes in anthropogenic noise loading can have large effects on the indicator variables.

Introduction

The National Park Service (NPS) is presented with the dilemma that it must develop its resources to provide access, yet preserve the resources in a substantially intact/unimpaired state (PL 88-578, 78 Stat. 897 § 460*l*-4). One example of the tension between providing access and ensuring preservation is road systems in protected natural areas and their associated road noise. Natural and cultural sounds are integral components of the suite of resources and values that the NPS is charged with preserving, restoring, and interpreting (Director's Order 47, 2000). Anthropogenic noise (e.g., transportation sounds), however, can obfuscate natural and cultural sounds as well as having negative ecological effects (e.g., Burger and Gochfeld 1998, Martin 1999). Together, natural and cultural sounds contribute to the sense of "naturalness" of a protected area. Research efforts across a variety of national park settings suggest that the quality of visitors' experiences is tied to the naturalness of the area's soundscape (Manning et al. 2006, Tranel 2006, Miller 2002). For example, findings from a recent study in Haleakala National Park suggest that the primary reason for visitors to take an overnight backcountry trip in the park is to experience the sounds of nature (Lawson et al. 2008). Human-caused sounds from aircraft, roads, maintenance activities, and other visitors, however, commonly permeate park soundscapes, making natural sounds and quiet an increasingly scarce resource (Krause 1999).

Recently, the NPS has applied indicator-based, adaptive management to address soundscape management and planning needs (Pilcher et al. 2008). The NPS has recently begun to address soundscape planning and management issues through techniques developed for the comprehensive Visitor Experience and Resource Protection (VERP) planning framework (NPS 1997, Manning 1999). This carrying capacity framework provides a process for identifying numeric indicators and standards of quality. Indicators are measureable, manageable proxies for desired park conditions and standards of quality are numerical, percentage-based expressions of desired conditions for indicators. When indicator values approach or have crossed the thresholds established by their standards, predefined management interventions are deployed to correct the problem via adaptive management.

Within the context of natural sounds and quiet, the NPS' indicator-based, adaptive management process involves formulation and long-term monitoring of soundscape indicators and standards of quality. As an example, the NPS might specify a "human-caused noise-free interval" as an indicator related to providing visitors opportunities to experience natural sounds and quiet. A standard of quality for this indicator might specify that at least 90% of visitors will experience at least one human-caused noise-free interval of 15 minutes or more while day-hiking in a national park.

Soundscape-related indicators and standards of quality are now being developed at a number of national parks, but measurement of some indicators, including soundscape metrics that vary greatly spatially and temporally, is nontrivial (Lawson and Plotkin 2006, Ambrose and Burson 2004). For example, natural sound-levels fluctuate due to wind, air physical characteristics (e.g., density, temperature), land form and cover, and wildlife. One proactive solution that also accommodates the complexity and difficulty of anthropogenic noise measurement is computer modeling (Lawson et al. 2003, Wang and Manning 1999). Computer simulation models are useful in complex system decision-making and have been used in a wide variety of industrial, economic, and resource management contexts (Barton 1992, Lawson 2006, Pidd 1992).

More recently, computer simulation modeling has been linked with sophisticated sound propagation spatial modeling software--originally developed for municipal and transportation planning--for research purposes. This addition allows computer models to predict changes in simulated soundscapes deriving from various model input values, accounting for ground cover, terrain, visitor movement patterns, and sound sources. By this method, managers and researchers can describe existing soundscape conditions and forecast changes in soundscape conditions associated with alternative management scenarios before any changes are implemented in the field (Shechter and Lucas 1978, Potter and Manning 1984).

This proactive, quantitative approach proves useful in informing and defending potentially controversial plans and decisions. Consequently, computer models have been used at a growing number of parks since the mid-1970s (e.g., Lawson and Manning 2003, Cole 2005, Romesburg 1974). Furthermore, visitor use and noise modeling methods have been demonstrated to facilitate evaluation of varying management scenarios without needing to implement them beforehand, including the effects of alternative management actions on the conditions of indicator variables (Lawson 2003, Lawson and Manning 2003). Finally, the quantitative, documentary nature of modeling helps to provide a clear chain of evidence for public agency decision-making (Miller 2008).

Soundscape planning and management is a salient issue at Rocky Mountain National Park (RMNP) in Colorado. The park accommodates 2.8 – 3.2 million visitors each year, placing it among the busiest 25 national parks in 2007 (PUSO 2008). In order to accommodate high demand for recreation opportunities in the Bear Lake Road area on the eastern side of the park, RMNP has provided a shuttle bus system that transported approximately 156,000 passengers annually before 2001. Total visitors transported in 2006 grew to 270,000, a 73% increase in just 5 years (personal communication to Dr. Steve Lawson). In the hope of reducing vehicle congestion on the RMNP road network by reducing the number of private vehicles, the park's 2006 management plan update includes an initiative to expand shuttle bus service. While efforts to increase shuttle ridership while reducing personal vehicle miles driven in the park is expected to reduce traffic congestion and parking problems, it is less clear what effects such changes will have on other park resources and the quality of visitors' experiences. For example, reducing the total number of vehicles on the Bear Lake Road could reduce overall roadway noise in the Bear Lake Road corridor. Alternatively, a shift to a greater number of shuttle buses on the Bear Lake Road, which tend to be larger and louder than personal vehicles, could saturate the surrounding landscape with roadway noise, subsequently harming hikers' sense of natural quiet and causing impacts to wildlife in the area.

Visitor use and noise modeling technologies have been developed that are useful in this situation to understand soundscape-based changes that could be associated with transportation planning (e.g., Lawson and Plotkin 2006, Lawson 2006, Miller 2004, Roof et al. 2002). At RMNP, soundscape and GIS modeling can be used to construct virtual park transportation and hiking trail networks, then used to understand noise levels across the trails resulting from alternative shuttle service configurations and associated personal vehicle traffic. Specifically, the noise measurements can be simulated for remote or very busy locations at which such measurements in the field are prohibitively time-consuming or difficult. These assessments take shape according to the National Park and Recreation Act of 1978, specifying that park General Management Plans must include: "types and intensities of development… including visitor circulation and transportation patterns, systems and modes… associated with public enjoyment and use" (PL 99-625 § 604). Once the models are constructed and calibrated, their output for a given scenario can be used to regress input conditions (e.g., use level and transportation schedules) against variables of interest, in this case visitors' exposure to roadway noise while hiking (e.g., van Wagtendonk 1978, 2003).

The purpose of this paper is to investigate the use of visitor use and noise modeling tools to provide spatially precise, integrated information about soundscape conditions within a national park setting, as dependent on potential transportation planning alternatives. In particular, the paper presents work conducted at RMNP to model and map visitors' exposure to transportation-related noise while visiting attractions and hiking on trails in the Bear Lake Road corridor. The results of this work provide the NPS with a planning approach useful in forecasting soundscape-related indicators of quality in RMNP. In addition, this modeling approach is adaptable to other national park units facing similar planning needs.

Methods

The Bear Lake Road corridor serves a surrounding 62.5 mile trail network that provides access to scenic lakes, waterfalls, nearby pack trails, and connections to the wider park trail system. Most of the hiking activity within the study area is anchored at the road's western terminus parking lot, near Bear Lake (Figure 3-1).

The spatial extent of the modeling was fixed at the western extent of the Bear Lake Road corridor, including its four westernmost trailheads, Bear Lake, Bierstadt Lake, Glacier Gorge, and Storm Pass. This spatial extent bounds the complexity of the transportation and hiking networks to a manageable level in terms of both model complexity and data collection burden.

For the purposes of developing the transportation noise model and generating spatially precise estimates of visitors' exposure to noise from Bear Lake Road, four primary types of data were collected in RMNP during summer (July – August) 2008: 1) traffic volume, by vehicle classification; 2) sound-level data; 3) visitor hiking routes and 4) daily visitation counts, by trailhead. Continuous traffic counters were installed at three locations to measure directional traffic volumes at fifteen minute intervals during a two-week period (Figure 3-1).

Sound-level data were collected at seven locations over an eight-day period during the summer (Figure 3-1). The acoustical monitoring locations were selected to represent a range of soundscape environments within a typical day's hike from trailheads along Bear Lake Road. For example, monitoring sites ranged from a roadside pull-off at a scenic overlook to an alpine lake 1800 m (Cartesian distance) from the road. To collect data needed to calibrate the transportation noise model directly to traffic volumes, one of the sound-level meters was co-located within approximately 55 meters of the traffic counter installed north of the park-and-ride lot serving the study area. All eight acoustical monitors were configured to record a sound-level measurement at one-second intervals, and four of the monitors were also programmed to record one-third octave band sound-levels. All of the sound-level meters were calibrated prior to and after sampling using a hand-held calibrator.

Visitor hiking routes were collected on 13 sampling days between July 31 and August 14, 2008 via administration of SiRFStarIII-equipped Garmin GPS units to visitors at the four westernmost trailheads along the Bear Lake Road corridor (Bear Lake, Bierstadt Lake, Glacier Gorge, and Storm Pass). The GPS units were distributed to randomly selected visitor groups, stratified by hour, at the start of their hikes and collected at the end of hikes. Visitors not planning to end their hike at a staffed trailhead were excluded from participation and thanked for their time. Daily trailhead visitation was measured with mechanical trail traffic counters, calibrated with data from direct observation (Kiser, Lawson and Itami, 2007). Visitor groups were asked to complete a brief supplemental survey after returning the GPS units.

Noise Modeling and Mapping

Sound propagation modeling of the traffic noise data was conducted using the Cadna/A software made by Datakustik GmbH. The geographic scope of the noise model was a 14,000 m by 14,000 m square, with its northeast corner just north of the park entrance and east of the eastern park boundary. The model incorporated traffic volumes for the full extent of Bear Lake Road, as recorded by the automatic traffic counters. A digital terrain model was obtained from the USGS and converted into elevation contours to model the attenuation of roadway sound due to intervening terrain. Propagation algorithms found in the German RLS-90 standard were used within the software to model how vehicle sounds from Bear Lake Road permeates the surrounding landscape (Kaliski Duncan and Cowan, 2007). In particular, the model estimates how sound propagates from the roadway to gridded "receiver locations" specified by the model developer, taking into account intervening terrain, the absorption of sound by the ground, energy attenuation into the atmosphere, vegetation cover, and losses due to the geometric spreading of the sound wave emanating from the road. Within this study, sound pressure level estimates were generated for a grid of 492,000 receivers covering every 20 meters within the study area. The result is a grid of daytime (6:00 AM to 6:00 PM) average sound-levels representing the traffic sound conditions during the sampling period, adjusted for human sound perception characteristics (i.e., measured as A-weighted decibels). The grid data were then plotted for visual display via a noise contour map or raster as appropriate to depict the study area's soundscape conditions with respect to noise from Bear Lake Road.

Visitor Use and Noise Exposure Modeling

The GPS tracks of visitor hikes were imported into a geographic information system (GIS) environment (ESRI ArcMap 9.3) for error correction and analyses. The data were filtered for positional inaccuracies due to poor satellite constellations and signals interrupted by sharp topographic relief using ocular inspection, velocity filtration, and a modified epsilon band spatial statistics approach. Trip data split across multiple GPS-native files (active logs) were assembled into individual trips using NoteTab text processing software, Microsoft Excel 2007, PHP5, and file concatenation software. Attribute data including hiker movement speed, initial trailhead, and intended destination, were joined to the track spatial data using tabular joins in ArcMap.

To provide contrast, an alternative to the baseline noise environment scenario was created using 90%-scaled values of the baseline scenario. This alternative management scenario conservatively approximates the effect of reducing road noise by 10%. Statistics for hiker exposure to noise were computed for both scenarios. Spatial statistics tools within the GIS software were used to estimate the amount of time and distance visitors must hike from trailheads to experience alternative soundscape conditions. Estimates were also generated for the proportion of visitors who experience at least 15 minutes of natural sounds and quiet, as defined by two potential road noise thresholds, including ≤ 25 dBA (nighttime ambient natural sound-level) and ≤ 35 dBA (daytime ambient natural sound-levels). These two standards could be considered conservative and more permissive abstractions, respectively, of average daytime natural sound pressure levels, as no single standard has been developed to date for this study area.

Results

Results of counts conducted to measure daily visitation, by trailhead, suggest that the Bear Lake Trailhead receives the vast majority of visitor use in the study area (Table 1). The noise map developed based on Bear Lake Road baseline traffic conditions in Figure 3-2 depicts higher transportation sound pressure levels in "warmer" color tones and lower sound pressure levels in "cooler" tones. Further, the noise map depicts normalized use-weighted more heavily visited trail segments with thicker brown lines, and lesser used trail segments with thinner brown lines. The noise map suggests that transportation sounds from Bear Lake Road permeate the park's soundscape throughout the adjacent trail system. The noise is concentrated along the road and falls off sharply with distance. However, the extent of noise in the area requires some effort on the part of visitors to reach areas of natural quiet away from Bear Lake Road.

Modeling was used to enumerate current ("baseline") conditions and a hypothetical management "alternative" situation representing a conservative estimate of the effects of a model-wide 10 percent reduction of road noise. For example, model results suggest that under current baseline conditions, visitors following the most direct routes to natural quiet would have to walk almost 1 km (0.6 miles) from three of the four trailheads included in the study area to reach natural quiet as defined by road sound-levels ≤ 35 dBA (Table 2). Average trip distance was 4.57 km; about 95.7% of visitors traveled over 1 km during their hikes. Under the alternative management scenario, only two of the trailheads, Bierstadt and Glacier Gorge, require visitors to travel over 1 km to reach natural quiet at 35 dBA. On average, the 10 percent reduction in road noise resulted in a 34% reduction in distance required to reach natural quiet versus the baseline condition.

Summaries of the GPS track data indicate that visitors' average hiking speed is 0.55 m/s (1.2 mph). This hiking speed is somewhat lower than typical average hiking speeds for other areas, due to many groups' propensity to linger or move more slowly around attraction areas such as Bear Lake. This hiking rate, coupled with the hiking distance results, suggests that the typical visitor would have to hike more than 30 minutes to reach natural quiet defined by road sound-levels ≤ 25 dBA (Table 3) (GPS logs indicate the average visitor group spending about 138 minutes hiking). Visitors using alternate, less direct routes would require more travel time to reach natural quiet defined by road sound-levels ≤ 25 dBA, or, in some cases, never reach it. For visitors hiking under the alternative management scenario, hikers spend less time reaching natural quiet. However, the difference in hiking time from each of the trailheads is less than three minutes in all cases except Storm Pass, where travel time to natural quiet is halved (Table 3).

Using the 35 dBA noise threshold for analysis and baseline conditions, the results suggest that, on average, visitors spend a substantial majority (73.2 percent) of total hiking time in natural quiet (Table 4). However, visitors walking around Bear Lake will experience elevated levels of noise for most or all of their hikes, while visitors starting from the same trailhead but hiking to more distant lakes (e.g., Emerald or Nymph Lakes) will experience almost uninterrupted escape from road sounds. About 89 percent of hikers to the area began their hikes at the Bear Lake trailhead (Table 1), and 14.7% of participating visitors included Bear Lake as a primary destination in their hikes.

It is useful to assess whether visitors are able to experience substantive "episodes" of natural quiet (a potential indicator variable), e.g., for fifteen uninterrupted minutes. Results suggest that a majority (57.3 percent) of visitor groups in the study area are able to experience intervals of natural quiet for at least 15 continuous minutes under baseline conditions, using 35 dB as the threshold for traffic noise (Table 5). When examined by trailhead, the results provide further insight into visitors' soundscape experience and how it varies across the study area. Hikers near Bierstadt Lake almost never experience quiet for 15 continuous minutes (0.8 percent of groups) due to a common route running parallel to the road, but about half of Bear Lake groups (50.7 percent) do. Under the alternative management scenario, this proportion grows by 5 – 30 percent depending on the trailhead.

The spatial modeling results also provide insights into how soundscape experiences evolve throughout the course of specific hiking routes. For example, the noise profile depicted in Figure 3-3 is for a hiking route that begins at the Bierstadt Lake trailhead, travels to and around

Bear Lake (middle peaks in the noise profile correspond to the edge of the lake closest to the nearby trailhead and large parking lot), and then heads into the comparatively quiet backcountry.

Discussion and Conclusions

In the context of long term transportation planning and decision-making, it is useful to be able to quantify the effects of planning alternatives on soundscapes. Small changes from the baseline noise condition can have large ramifications. For example, hikers embarking from the Storm Pass trailhead could experience, following a 10% reduction in road noise, a greater than 50% reduction in travel time needed to reach natural quiet. However, it is important to note that the travel time differences between the baseline and alternative scenarios are not constant throughout the study area. Specifically, hikers departing from the Glacier Gorge trailhead would only experience a 5% reduction in travel time required to reach natural quiet. This difference in reductions is substantial because use is not evenly distributed among trailheads, i.e., more than three times as many visitors use the Glacier Gorge Trailhead as compared to the Storm Pass Trailhead. Thus dramatic changes enjoyed in one area are not necessarily a benefit to all recreationists.

Since use is not evenly distributed among trailheads, it is important to interpret the model predictions in light of the spatial distribution of use vis-à-vis the spatial variation in soundscape. For example, the minimum distance to natural quiet varies across the trailheads in the study area by approximately a factor of two. This characteristic of the study area suggests opportunities for management to highlight specific trails to visitors that provide greater opportunities for natural sounds and quiet.

With respect to measuring those opportunities for quiet, it is important to select potential indicator measures carefully, based on a clear understanding of how different indicators reflect the experiences of visitors in subtly varying ways. For example, Table 4 reports that the relative magnitudes of percentage of time spent in natural quiet for Bear Lake and Bierstadt Lake hikers are consistent across decibel thresholds and modeled scenarios. Specifically, hikers embarking from Bear Lake spend varying time in natural quiet, but on average spend consistently more than do hikers from Bierstadt Lake. This relationship holds true for the corresponding entries in Table 5, except at the 35 dBA category for the baseline scenario, where a higher proportion of Bierstadt Lake hikers experience quiet (51.4%) than do Bear Lake hikers (49.6%). To understand why, it is important to understand how the variables are calculated. Average time spent in quiet (Table 4), as an indicator variable, simply amasses the instantaneous sound-levels for each given hiker at all recorded locations. Percentage of visitors experiencing at least 15 uninterrupted minutes of natural quiet (Table 5), is a more "fragile" indicator in the sense that it is more difficult to amass 15 minutes of quiet than it is to find it, lose it, find it, etc. as one hikes along. As a result, hikers near Bear Lake (located near the large, busy Bear Lake parking lot) have a relatively more difficult time on average achieving continuous quiet than do hikers from Bierstadt Lake. Therefore, spatial arrangement of trails within a soundscape plays an important role in determining which indicators are appropriate in a given setting, with respect to the management goals involved. It is interesting to note, however, that Bear Lake visitors on average experience a lower time-weighted average noise level (28.5 dBA) than do Bierstadt Lake hikers (36.0 dBA). This result contrasts the above finding, but is attributable to the same reasoning. Bierstadt Lake hikers tended to follow a route paralleling the road but that stayed just outside the 35 dBA noise coverage. Bear Lake hikers, on the other hand, tended to head deeper into the backcountry, traveling away from the road.

With regard to the hikers that participated in the study it is useful to note that, on the way to building datasets for understanding hiker routes through soundscapes, one can better understand hikers in this context from a geospatial perspective. For example, hikers in this area hiked comparatively slowly on average (0.55 m/s), bringing an appreciation of the effect of the many hikers that enjoyed a slow walk around Bear Lake. In addition, the aggregated GPS data lend other useful insights: the relative popularity of trail segments, popular routes, and in a few cases, common places for off-trail exploration. It should be noted, however, that the consumer-grade GPS units handed out to visitors in this study did not have positional accuracy sufficient to document short off-trail excursions.

It is important to note that the time and distance required to reach natural quiet defined by road sound-levels ≤ 30 dBA may present difficulty for less-mobile visitors seeking to get away from transportation noise. While the statistics suggest that most hikers spend a majority of time in natural quiet, it should not be overlooked that the easiest, accessible hikes are closest to the road and consequently saturated in road noise (e.g., Bear Lake loop). By extension, it is useful to note that places where people tend to travel more slowly may be more important because the "noise dosage" there is extended.

Finally, the prevalence of opportunities to experience natural quiet is also sensitive to the manner in which natural quiet is defined. For example, natural quiet defined as roadway sound-levels of 25 dBA or less is experienced by virtually no visitors (0.6 percent) in the Storm Pass area in the baseline scenario. By defining natural quiet at 35 dBA, however, the proportion of visitors experiencing quiet grows to 39.5 percent. This example illustrates the powerful effects of small changes to baseline noise standards. Under the alternative management scenario (i.e., 10 percent reduction in noise), the percentage of time spent in natural quiet more than doubles for visitors embarking from Bierstadt Lake trailhead and grows by a factor of 30 to 18.2 percent for visitors embarking from Storm Pass trailhead. This research is one step toward answering, "how much noise is too much?" for the study area but it illustrates the endeavor's potential sensitivity to small changes in standard levels.

Managers should highlight soundscape opportunities for visitors interested in experiencing natural quiet. One means in which this might happen is through emphasis of quieter, less crowded trailheads by park interpretive staff that accompany visitors on the shuttle busses en route along Bear Lake Road. Additionally, trails that pass through the noise "shadows" created by topography could be emphasized. Glacier gorge is a fitting example; it is comparatively low use and, beyond Alberta Falls, is routed around topography that effectively shields hikers from road noise. It should be noted, however, that alerting hikers to opportunities of natural quiet necessarily involves tradeoffs. Supplementing current traffic on any trail is bound to increase noise associated with other hiker groups (though this noise source was not modeled in this project).

This article describes several potential noise indicator variables (average time spent in natural quiet, percentage of hikers experiencing 15 uninterrupted minutes of natural quiet, et al.), and two potential thresholds derived from local soundscape characteristics. However, there is an opportunity to develop general guidelines for maximum acceptable noise levels in protected areas (Roof et al. 2002). In addition, pairing GPS-based visitor use data with soundscape modeling in a GIS environment enabled detailed quantitative insights on the potential effects of management alternatives on indicators for transportation amenities. However, use of GPS technology superior to the consumer-grade units used in this research study would have increased sample sizes and spatial resolution of hiker data. Also, prescriptive research should be performed in this context to understand the experiential side to the issues explored in this paper, and to better understand what values should be used for noise thresholds. Finally, the spatial modeling described in this paper regards only a subset of RMNP. Additional research should be pursued to investigate use and sound dynamics with respect to transportation in other areas of the park and in other settings more broadly. Doing so will further advance understanding of the complex interplay of sound, visitor experiences, and transportation management in protected areas.

Tables

Table 3-1. Average daily visitation and proportion of total visitation to study area, by trailhead.

Trailhead	Average Daily Visitation	Proportion of Total Visitation
Bear Lake	7,353	89.1
Bierstadt Lake	96	1.2
Glacier Gorge	638	7.7
Storm Pass	170	2.1
Total	8,257	100.0

Table 3-2. Hiking distance from trailhead required to reach closest substantive natural quiet, by trailhead and noise threshold.

	Baseline Distance (m)		Alt. Scenario Distance (m)		% Reduction for
Trailhead	**25 dBA**	**35 dBA**	**25 dBA**	**35 dBA**	**35 dBA Standard**
Bear Lake	1093	155	1012	98	36.8
Bierstadt Lake	1934	1542	1633	1529	0.84
Glacier Gorge	2097	1210	2086	1149	5.0
Storm Pass	1907	973	1442	448	54.0

Table 3-3. Average hiking time from trailhead required to reach natural quiet, by trailhead and noise threshold.

	Baseline Travel Time (minutes)		Alt. Scenario Travel Time (minutes)		
Trailhead	**25 dBA**	**35 dBA**	**25 dBA**	**35 dBA**	**% Reduction for 35 dBA Standard**
Bear Lake	33.1	4.7	30.7	3.0	36.8
Bierstadt Lake	58.6	46.7	49.5	46.3	0.84
Glacier Gorge	63.5	36.7	63.2	34.8	5.0
Storm Pass	57.8	29.5	43.7	13.6	54.0

Table 3-4. Percentage of hiking time visitors experience natural quiet, by trailhead and noise threshold.

	Baseline Percentage of Hiking Time		Alt. Scenario Percentage of Hiking Time	
Trailhead	**25 dBA**	**35 dBA**	**25 dBA**	**35 dBA**
Bear Lake	54.5	77.8	60.4	81.4
Bierstadt Lake	12.1	43.7	27.4	46.7
Glacier Gorge	60.2	74.1	61.3	85.8
Storm Pass	0.6	39.5	18.2	40.1
Study Area-Wide	53.8	73.2	58.2	80.5

Table 3-5. Percentage of visitors experiencing at least 15 minutes of quiet, by trailhead and noise threshold.

	Baseline		Alternative			
Trailhead	**25 Db**	**35 Db**	**25 Db**	**35 Db**	**n**	**% of arrivals**
Bear Lake	26.0	49.6	61.8	69.9	123	89.1
Bierstadt Lake	5.4	51.4	43.2	56.8	37	7.7
Glacier Gorge	45.3	59.4	64.2	75.5	106	1.2
Storm Pass	0.0	33.3	33.3	66.7	3	2.1
Total	24.1	49.6	59.9	70.3	269	100.1*

*Total includes rounding error

Figures

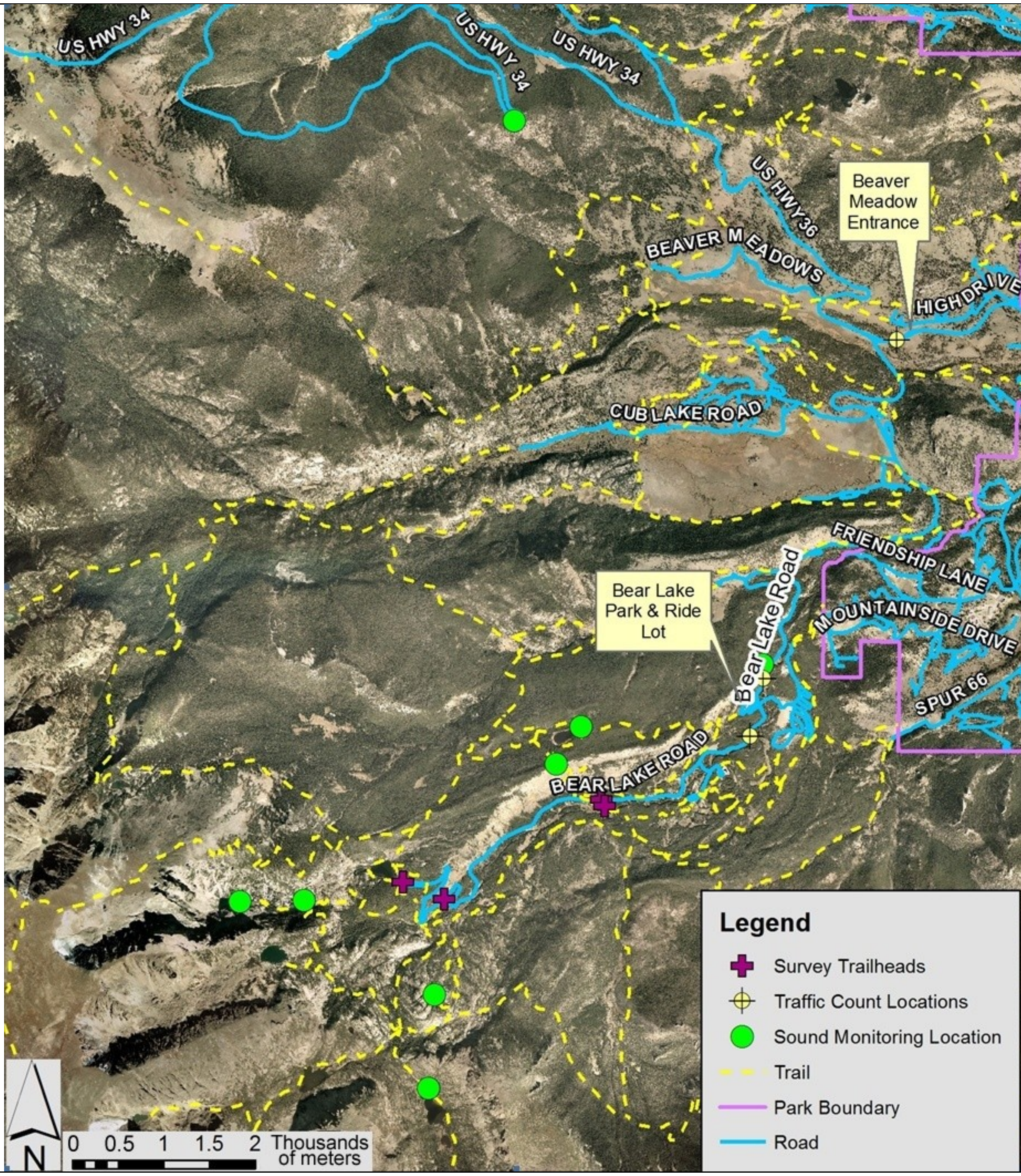

Figure 3-1. Study area, including traffic volume, sound-level, and GPS-based hiking route monitoring locations.

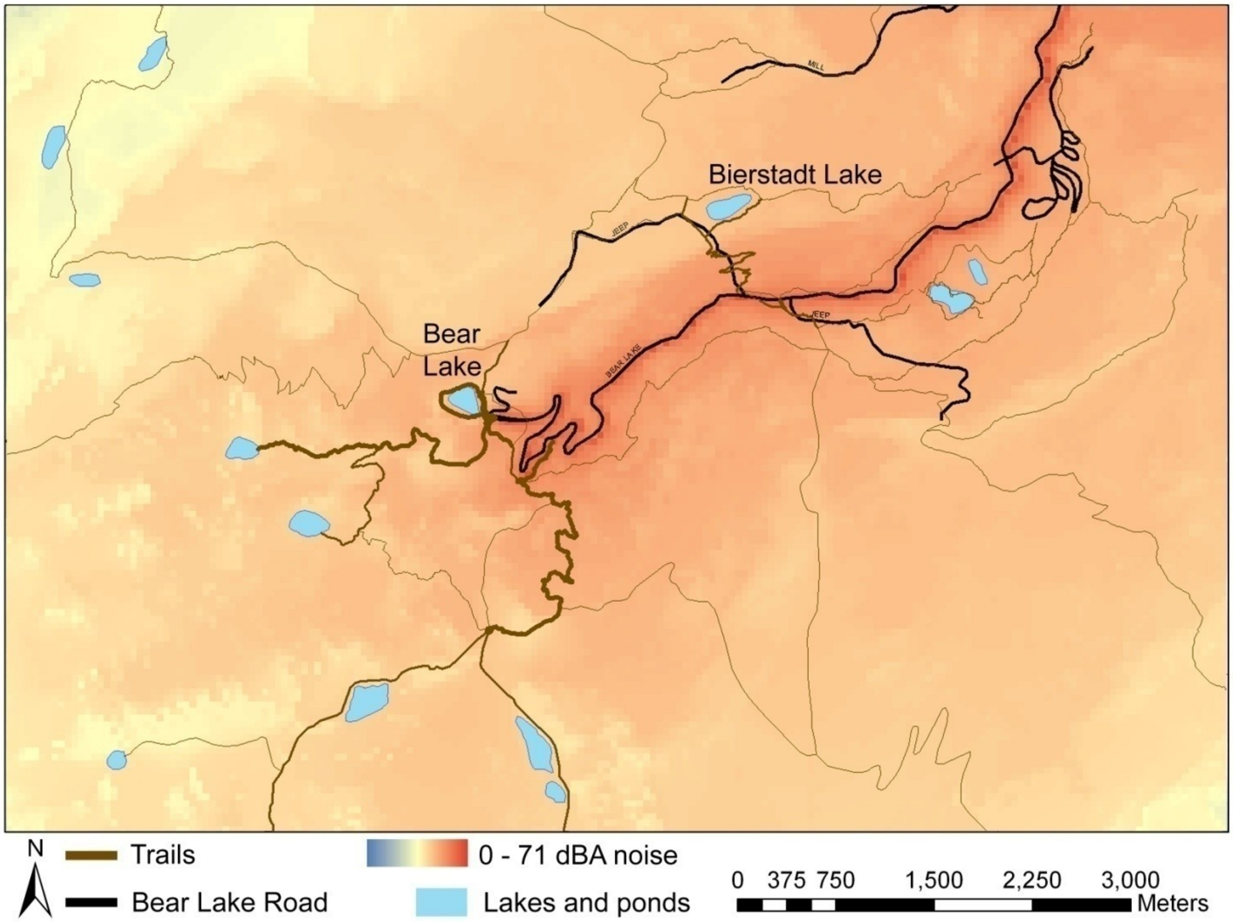

Figure 3-2. Noise map of baseline traffic volumes on Bear Lake Road and relative intensity of hiking use on adjacent trail network.

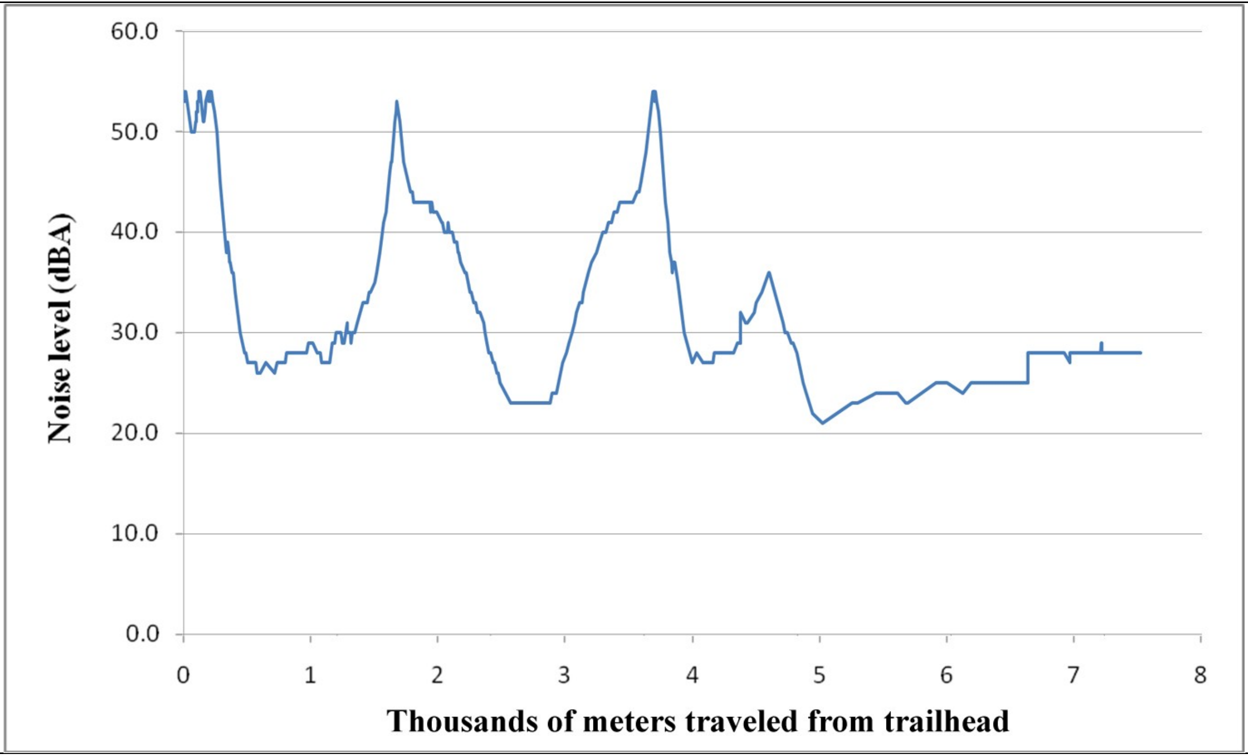

Figure 3-3. Noise level profile for hiking route from Bierstadt Lake Trailhead, to and around Bear Lake, and into the park's backcountry.

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Efficacy of Indirect and Site Management Techniques in Reducing Off-Trail Behavior in a Fragile Biotic Community, Acadia National Park

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ABSTRACT

Striking a balance between resource protection and visitor experience is a perennial challenge for protected area managers. Some level of resource degradation must be tolerated to allow any recreational use at all, but even low levels of foot traffic can reduce vegetation cover, pulverize and remove organic litter, and increase the erosion potential of the underlying soils (Bradford and McIntyre 2007, Bayfield 1973, Cole 1995a, Olive and Marion 2009). In this companion paper to a 2008 article by Park et al. on efficacy and acceptability of adaptive management measures designed to discourage depreciative off-trail behaviors in a high use frontcountry setting, additive combinations of management techniques are evaluated for efficacy in a high use backcountry trail setting. Combinations including site management and information/education that address multiple motivations for off-trail behaviors are shown to be effective at reducing off-trail travel rates. However, a more-direct, obtrusive measure that relied on fewer additive components—low symbolic post-and-rope fencing—was shown to be the most effective among all treatments studied. Data were collected by a closed circuit video recording system assembled in the backcountry and powered by a deep cycle battery.

Resource Impact, Resource Protection

Striking a balance between resource protection and visitor experience is a perennial challenge for protected area managers. This issue is particularly salient for those working in national parks, where visitor use measured in millions of visits per year can lead to substantial ecological and experiential impacts. Therefore, investigations of effective management approaches that prevent (or minimize) visitation-associated impacts can provide valuable information and assistance in visitor experiences and resource conditions.

For protected areas that receive high levels of visitation, the management of the effects of foot traffic and associated trampling impacts are particularly acute. Some level of resource degradation must be tolerated to allow any recreational use at all, but even low levels of foot traffic can reduce vegetation cover, pulverize and remove organic litter, and increase the erosion potential of the underlying soils (Bradford and McIntyre 2007, Bayfield 1973, Cole 1995a, Olive and Marion 2009). Repeated off-trail excursions create and proliferate informal visitor-created trails. Over time, short cuts and additional access routes are cut across vegetation and exposed soils (Johnson and Vande Kamp 1996). When visitors go off-trail or use informal trails, they can accelerate the spread of exotic invasive species into native biotic communities (Cole 1995a). Low levels of off-trail travel lead to compositional and species richness changes as fragile species are crushed underfoot (Frissell and Duncan 1965). These species (esp. ferns and other nonwoody herbs) are not resistant to impact and can be severely impacted in a single season of consistent use. Further off-trail travel slowly overwhelms more resilient species as stored resources are channeled into tissue repair. Eventually trampled areas suffer reduced biomass and vegetative cover (Cole 1995b, Sun and Liddle 1993). Continued use exposes soil by pulverizing surface organic litter into fragments and further into humus, which is easily removed by wind or overland water flow. With reduced organic covering to cushion impacts, exposed mineral soil is made susceptible to erosion in a positive feedback cycle (Monti and Mackintosh 1979). At this stage, recovery to an "unimpacted" state can occur on a geologic timescale in some places. Localized impacts can vary in size; considered across the scale of a trail network or national park, the aggregate impact can be immense (Lawson and Manning 2002). Moreover, informal trails are quick to appear and slow to recover (Cole et al. 1997). Managers seek to limit trampling impacts by concentrating visitor traffic to networks of formal trails and designated recreation sites designed to accommodate intensive use. However, visitors frequently venture off or away from these designated trails and sites, expanding the boundaries and aggregate area of intensive trampling disturbance and creating new informal or visitor-created networks of trails and recreation sites (Leung and Marion 2000).

Accommodating more than two million visits every year since the 1960's, Acadia National Park (ANP) is an example of these visitor impact management challenges (PUSO 2008). ANP is among the most visited national parks in the United States, and due to its comparatively small size, less than twenty thousand hectares, its density of use is exceptionally high. As a result, ANP has experienced substantial use of its popular icon areas—with associated trampling impacts—in recent years.

The Gorham Ridge Trail is one such area. Hundreds of hikers enjoy this high-use, backcountry trail each day during peak season use (personal communication to Jacobi 2007). The trailhead is vehicle accessible from the high-use park loop road, offers commanding views of coastal Maine and the ocean, and features short and comparatively easy hikes to these views. Unfortunately, a small proportion of Acadia's visitors in past years have evidenced a functional understanding of "Leave No Trace" principles, an international program of low impact practices and ethics adopted by ANP management (Evans 2002, Turner and LaPage 2001).

Gorham Ridge Trail hikers frequently venture off-trail once they pass the lower forest vegetation and reach the more open summit environment, characterized by exposed bedrock with thin lenses of soil and low shrubby or grassy vegetation. Trampling of the fragile subalpine vegetation and soils is a significant management concern and challenge for park staff (Turner and LaPage 2001). The thin granitic soils overlying the summit bedrock regenerates slowly given the harsh weather conditions and the bedrock's natural resistance to erosion/soil generation processes (Davis 1966). Because of these thin soils and adverse weather, the "heath summit dwarf shrubland mosaic complex" in the area grows and regenerates slowly from foot traffic impacts and may be more vulnerable to exotic invasive incursion (Turner and LaPage 2001, Leung et. al. 2002). A century of off-trail exploration, photography, and blueberry picking has resulted in substantial, immediate, and long-lasting resource degradation (Liddle 1997, Baldwin and LaPage 2003).

Responding to these impacts, park management has erected trailhead maps and educational signage encouraging low-impact behaviors seeking to persuade hikers to remain on the formal trail or on durable rock surfaces. In addition, park managers have erected pagoda-like Bates rock cairns at regular intervals and used paint blazing in an attempt to clearly mark the designated path. However, the literature suggests that the success of these measures can be improved through adaptive management, an iterative process of flexible and "deliberately experimental" refinements to management practices (Walters 1986, Walters and Holling 1990). As successive trials of management interventions are applied in light of the insights gained from past trials, resource protection is improved. The process relies on "incremental knowledge growth" to adequately manage dynamic natural and social systems as an ongoing series of experiments (Reid 2003). This study seeks to enrich the small corpus of research on adaptive management approaches to trail-proximate resource protection in a backcountry setting.

A companion study of this research was undertaken to examine similar concerns at a popular frontcountry site at ANP, the summit of Cadillac Mountain (Park et al. 2008). Several thousand visitors access the summit each day, spreading out from a short, paved summit loop trail onto bedrock, exposed soil and patches of vegetation. That research suggests that particular combinations of site management and information/education management approaches may be effective in enhancing the protection of the area's biota and soil without unduly burdening the visitors' experiences there. However, measures appropriate and effective for a frontcountry setting (as investigated by the companion piece) may not be appropriate for a backcountry setting as studied on Gorham Ridge and places like it. Another study at ANP by Cahill (2003) examined the suitability of a range of management interventions in terms of frontcountry versus backcountry settings. Cahill's stated choice analyses found that setting had a strong effect on the acceptability of management actions arranged along a spectrum of "naturalness." Specifically, management actions that reduced the natural aesthetic were less acceptable in backcountry settings than they were in frontcountry settings. Similarly, management interventions that increase visitor encounters between groups were more acceptable to respondents for frontcountry settings than for backcountry settings. This important finding suggests that areas of degraded environmental quality in the backcountry should not be managed in the same way as analogous impacts in the frontcountry. But which measures are effective at reducing depreciative behaviors along trails in the backcountry? Measures must first be found effective before they can be considered for their potential experiential impacts or setting suitability.

This research explores the protection effectiveness of a variety of measures drawn from management strategies and tactics suggested in the literature, though few basic research studies exist to examine the effectiveness of combinations of site management and educational messages in preventing trailside resource degradation. This information could prove invaluable in protected areas land management. The findings of this study may be useful to other land management agencies as well as larger private organizations that manage publically accessible lands.

Management Frameworks

The literature describes several frameworks or strategies useful in constructing management options for limiting off-trail travel. One management framework groups impact-mitigation tactics into four broad strategies: (1) reducing use via permit requirements or restricting access; (2) increasing the supply of the resource by distributing use and making more of the area accessible; (3) reducing use impacts by altering uses, e.g., restricting type of use or behavior or educating visitors about high-impact practices; or (4) hardening the resource to better accommodate use with limited impact, e.g. installing gravel or rockwork to a trail (Manning 1999). However, not all techniques within this framework are feasible or appropriate to the aesthetics or experiences associated with a given protected area management unit.

Specific techniques derived from one of this fourfold framework's strategies (or combination of strategies) for protecting natural and experiential resources may in several ways affect visitors' experiences while recreating (Park et al. 2008). For example, techniques that limit use may be received unfavorably by visitors, given that such techniques generally reduce the perceived freedom of recreationists. Just as importantly, use-limiting techniques can entirely exclude some recreationists from being able to access a recreation area. Also, management techniques that are appropriate for one site may not be appropriate for another in terms of aesthetic considerations or the recreation opportunities of the site (Cheung 1972). For example, fencing may be appropriate for reducing off-trail behaviors at frontcountry cultural and archaeological sites, but wholly aesthetically inappropriate in most backcountry settings. In addition, the management strategy used can affect perceptions of crowding (Shelby, Vaske, and Heberlein 1989). One example is the effect of alternative spatial arrangements of parking lots that concentrate or disperse equivalent numbers of visitors. Thus, it is important for managers to select techniques that are appropriate and minimally obtrusive on recreation experiences.

Another way of organizing management approaches is to locate them on a spectrum of direct to indirect actions (Gramann, Christensen, and Vander Stoep 1992; Manning 1999). Direct management actions target visitors' actions and associated outcomes (Manning 1999, Crandall 1980). Common direct management actions include fining noncompliant visitors, site management measures such as restrictive permitting schemas. At Gorham Ridge, one example of direct techniques could include use of low native stone scree walls as a visual cue of trail boundaries in exposed bedrock areas where only erosive, degraded soil (which can appear to visitors to be a thin gravel) is present to fill this role. Site alterations, posted use regulations, and other direct techniques are often effective in changing visitor behaviors but can be aesthetically intrusive or perceived to impair visitor freedom (Wohlwill and Harris 1980, Carls 1974). The aesthetic intrusion may even be tied to effectiveness. A previous study demonstrated that wooden split rail fences were less effective at keeping visitors on a trail than were less-attractive yellow nylon rope fences, even though the wooden fencing was more physically substantial (Swearingen and Johnson 1988). This tradeoff of aesthetics/perceived experience quality versus impact prevention is a common issue with site management techniques.

Indirect management actions, by contrast, seek to prevent depreciative behaviors by influencing visitor reasoning and decision-making, for example through information/education measures designed to increase awareness of the consequences of specific visitor behaviors (Gramann Christensen and Vander Stoep 1992; Gramann and Vander Stoep 1986). Previous studies have suggested that most depreciative behaviors by visitors are the result of uninformed behavior, not of malicious intent; such behaviors are thought to be effectively remedied through information/education management approaches (Eagly and Chaiken 1993, Harrison 1992, Namba and Dustin 1992). Common examples are the use of educational messages to inform and appeal to visitor ethics as a persuasive technique. For example, Roggenbuck and Berrier (1982) found that informational pamphlets had a significant effect on altering visitor dispersal at a crowded park location. Managers often prefer indirect techniques for the simple idea that they are less conspicuous in the visitor experience (Manning 1999). However, indirect techniques are sometimes perceived by managers as less effective than direct techniques, and in some cases have been empirically demonstrated to be less effective (e.g., Alessa Bennett and Kliskey 2003). This perception has been substantiated in the literature as well (Park et al. 2008).

A degree of synergy may exist between direct and indirect techniques; combinations of direct and indirect techniques may be more effective in reducing noncompliant visitor behaviors (Johnson and Swearingen 1992, Roggenbuck and Berrier 1982). A study of off-trail behavior at a hiking area in the Blue Ridge Parkway found that closing informal trails through sensitive habitat through various kinds of brushing (i.e., site management) was not effective (Johnson Bratton and Firth 1987). Brushing the informal trails (without information/education present) not only failed to close the trails, but overall impact also increased as some visitors went through the brushing (keeping the trails open) and other visitors went around the brushing, creating new impacts in the sensitive biological community there. Again, managers must take care to ensure that an incorporation of a variety of techniques is not too burdensome or intrusive on the visitor experience. In the example of the brushing at the Blue Ridge Parkway hiking area, information/education measures may have helped visitors to understand why off-trail areas were being closed for restoration.

Regardless of any specific combination of techniques, careful thought must be given to ensuring that the measures in place address a variety of motivations for going off formal trails (Gramann and Vander Stoep 1987, Christensen and Dustin 1989, Knopf and Dustin 1992). Past research has suggested that such motivations can range from unintentional or accidental reasons (e.g., difficulty in distinguishing between formal and informal trails), through "releaser cues" (e.g., going off-trail after reaching informal trail junctions or seeing others already off-trail), to intentional/purposive off-trail behavior (e.g., traveling to a vista outcrop not routed with a formal trail) (Gramann and Vander Stoep 1987).

Research has suggested that indirect information/education approaches may be effective in changing careless or unintentional behaviors. However, direct measures are appreciably more effective at curbing intentional depreciative behaviors (Swearingen and Johnson 1994, Johnson and Swearingen 1992). For example, earlier research at Acadia's nearby Cadillac Mountain summit found that tall wooden exclosures protecting patches of sensitive vegetation were highly effective, but appeared to suggest to visitors that all other areas of the summit (including unnaturally exposed soils and other vegetation patches) were acceptable for visitor foot traffic (Baldwin and LaPage 2002). Thus, it is important to make certain that the messages presented to visitors are explaining site management measures in place.

Additional useful means of enhancing message effectiveness lie in communication theory. Specifically, the route to persuasion construct examines how messages are evaluated by people on the bases of content (central route to persuasion) and/or delivery (peripheral route to persuasion) (Manning 1999, 2003). Several studies have suggested that message delivery through personal contact with protected area authorities can be among the most effective means at engendering a desired visitor behavior (e.g., Fennell 2001). In an ANP context, an emphasis on delivery might involve a uniformed ranger asking visitors to remain on the paved trail. One cost-reducing approach might be to utilize official-looking logos and organization identification in an attempt to access some of the same sense of authority wielded by uniformed park employees. Similarly, a more formal or prominently placed sign by itself communicates a stronger message than a less formal one with identical wording (Baldwin and LaPage 2002). However, emphasis of the central ("substantive") route to persuasion has been suggested to promote more lasting changes in behavior (Manning 1999). As a result, it is important to maximize messaging effectiveness through both routes to persuasion.

Methods

Study Area

Gorham is a popular backcountry mountain summit rising 525 feet above sea level with parking lot access along the busy and popular Ocean Drive Road. The trail's 1 mile length receives approximately 400-600 visitors per day during the summer season. The Gorham Mountain trail is the only trail over the summit, and it is marked by Bates-style rock cairns and paint blazes to help visitors navigate and remain on-trail. Off-trail hiking, while permitted to extend visitors maximal recreation freedom, is a concern because the subalpine vegetation is relatively fragile and recovery rates are low due to the shallow dry soils in the area.

A park summit steward volunteer noted that visitors often interpret eroded, exposed patches of subalpine soil along trails and at summits in the park as legitimate foot trails. Above tree-line on the mountain, informal (visitor-created) trails occur at vistas and in other flatter areas, with vegetation and soil loss caused by decades of intensive visitor trampling. Previous surveys by park staff have also found that the cairns used to mark the trail are under continual disturbance by visitors, adding to safety and navigation concerns. Less than 40% of cairns survive five days without alteration during the peak season (Jacobi 2003).

The objective of this study was to test the relative effectiveness of adaptive management-style combinations of educational and site management actions on reducing off-trail behavior along a high use backcountry foot trail. The efficacy of alternative treatment combinations of these actions was assessed through videography because use levels were too low to allow for the effective use of human observers. The study's observation site was selected based on availability of concealing vegetation for video equipment used to record video data, the variety of trail environs visible (and differing hypothesized motives for possible off-trail travel), and the high level of localized off-trail resource degradation. Hypothesized motives for off-trail travel include getting around other visitors, exploring, accessing vistas, and shortcutting (Park et al. 2008).

Treatments

This study tested a variety of educational messages and site management techniques in combination through an experimental, behavioral design. The practices used in the study were selected based on a review of the literature and consultations with park managers in a collaborative and adaptive management process. The overriding goal was to substantially reduce off-trail hiking. Combinations of actions were expected to have higher efficacy than single actions. Table 1 summarizes the control and experimental treatments undertaken in this study and the specific management techniques involved in each treatment.

Control (Baseline) – To mimic baseline existing conditions, rock cairns were placed along the trail at intervals ensuring that one was visible to hikers regardless of position and direction of travel. Any border rocks that had been placed previously for trail management were removed. The tread of the trail itself was left unchanged in this and all subsequent treatments. There were 10 pre-existing paint blazes on the trail's bedrock surface during the control period. No educational signage was present during this treatment.

Treatment 1 (Blazing) – The rectangular paint blazes marking the trail were supplemented with additional similarly colored and sized temporary blazes constructed from adhesive tape (n = 13). The blazes were set at short intervals (5 – 10m) to ensure that multiple blazes were visible regardless of hiker position and direction of travel. Rock cairns were removed. Beyond the upper end of the study area, additional tape blazes (n = 6) were placed along the trail to the summit to encourage as many hikers as possible to enter the study area on the formal trail. No educational signage was present during this treatment.

Treatment 2 (Educational Signs) – Large educational signs were placed at each end of the trail study area (Figure 4-1). Sign text included prescriptive injunctive (i.e., what visitors *should not* do), attributional language: "Leave No Trace of your summit visit. Your footsteps damage fragile plants and animals. Please: do not leave paint-blazed trails. Do not move rocks." The message featured Leave No Trace language as a tie-in to a broader national program and to convey the intended personal outcome. The educational signs included the NPS arrowhead logo to emphasize the official authority of the message. Rock cairns were placed along the trail at intervals ensuring that one or more was visible to hikers regardless of position and direction of travel. Additional temporary blazes were placed as in treatment 1 (blazing). Additionally, approximately 10 small trailside prompter signs (Figure 4-2, inset) were placed on informal, visitor-created side trails wherever they joined the formal trail study area. Two additional prompter signs were placed along the trail to the summit to encourage as many hikers as possible to enter the study area while on-trail.

Treatment 3 (Coping Stones) – Large native stones (8-24"dia.) were placed on opposite edges of the trail; these stones were spaced along the trail at 6 foot intervals to create a continuous visual trail border across the study area's open bedrock. From the oblique viewing angle of hikers along the trail, the discontinuous coping stones more clearly delineated the boundary of the trail. Rock cairns were placed along the trail at intervals ensuring that one or more was visible to hikers regardless of position and direction of travel. No educational signage was present during this treatment.

Treatment 4 (Scree Wall) – Native stones were arranged as a continuous trail border throughout the study area, enough to cover the extent of the upper half of the study area. As with treatment 3 (coping stones), the rocks were large enough to create a clear visual demarcation of the trail treadway, but small enough that they were not a physical barrier. Rock cairns were placed along the trail at intervals ensuring that one or more was visible to hikers regardless of position and direction of travel. No educational signage was present during this treatment.

Treatment 5 (Symbolic Fencing) – Low rope fencing was installed with 0.5m wooden stakes along both sides of the upper section of the study area. As in treatment 4, the fencing was a symbolic visual cue, not a physical barrier. Rock cairns were placed along the trail at intervals ensuring that one or more was visible to hikers regardless of position and direction of travel. No educational signage was present during this treatment.

Treatment 6 (Integrated) – This additive treatment incorporated several of the above treatments' measures, using the educational signage placed at both ends of the study area, the rock cairns, coping stones, and trailside prompter signs.

Data Collection

Video surveillance equipment was unobtrusively installed across the study area to evaluate the efficacy of each treatment. Three color closed-circuit weatherproof video cameras were trained on sequential segments of the study area. Each camera was oriented to provide a clear view of the trail without providing individually identifying features of the hikers. A fourth camera recorded a field of view of the lower educational signage for those treatments incorporating the sign. All cameras were wired to a digital video recorder unit and all were powered by a deep-cycle gel battery and configured through an electric timer to continuously record data during peak use hours. Field staff periodically reviewed footage to ensure system functionality, created field data backups to DVD, and replaced the battery as necessary.

The control and treatments were applied for up to four randomly selected days during a period of six weeks in July and August 2008, corresponding to peak season use levels. Video data were collected during fair weather days and peak use hours, from 9 am to 6 pm. Sample sizes for treatments and controls ranged from 686 to 1261 visitors, total headway (Table 1). Hikers were not counted as going off-trail unless they had first traveled any distance on-trail within the study area to ensure that they were making a decision to go off-trail in contravention of the treatment or control in place. Some hikers observed entering the study area in the downhill direction were likely hikers who had previously entered the study area in the uphill direction, though not all visitors share this itinerary.

At the conclusion of fieldwork, the video footage was evaluated for off-trail behaviors according to location, direction of travel, extent to which the visitor went off trail (i.e., "near off" within 6 feet of the tread or "far off"), time of day, and weather conditions (i.e., rain, wind, visibility). For treatment 2 (educational signage) additional data were collected to characterize how long each individual uphill-bound hiker spent reading the sign at the lower end of the study area, how often cairn and border rocks were disturbed, and (where possible) the apparent reasons for hikers going off-trail.

To ensure data transcription quality, evaluators were trained in video interpretation techniques and used transparent screen overlays to clearly demarcate the different visual zones for each camera's field of view. In addition, the evaluators used slow motion review where necessary. Inter-rater reliability tests were performed among the teams of video evaluators with no significant differences found. Exceptional and ambiguous situations were flagged by the evaluators and scrutinized further as necessary.

The observation data were processed in Microsoft Excel from hourly totals of off-trail behavior to off-trail rates through a series of Visual Basic automating macros, then analyzed in SPSS for statistically significant differences among treatments and the control.

Results

The rates for off-trail travel by treatment are shown in Table 2. Off-trail rate reductions were examined at two ranges of distance from the formal trail, less and more than 2m distance, based on literature suggesting that off-trail behavior can occur for differing motivations, resulting in differing degrees of behavior (Park et al. 2008). For example, a visitor attempting to pass a group of other visitors might tend to stay close to the formal trail. By contrast, a visitor seeking a vista may go further off-trail. Approximately 1 in 2 visitors (49.9%) went off-trail no more than 2m from the trail under control conditions. The coping stones treatment reduced off-trail rates to 48.3% of visitors, a reduction that was not significantly different than the control result ($\chi^2 = 0.667$, $p = 0.414$, 1 df, n = 2438). The symbolic fencing treatment provided the greatest reduction of off-trail behavior, to 11.1%, from control conditions. This reduction was highly significant ($\chi^2 = 323.3$, $p < 0.001$, 1 df, n = 1992). Direction of travel was not found to have a significant effect on off-trail rates for any individual treatment.

Results for treatment efficacy were generally similar for off-trail behavior beyond 2m from the formal trail (Table 2). Blazing ($\chi^2 = 1.029$, $p = 0.310$, 1 df, n = 2021), as with off-trail travel within 2m of the formal trail, did not reduce off-trail travel to a rate differing from the control. The coping stones treatment did have a highly significant effect on off-trail travel rates beyond 2m from the formal trail ($\chi^2 = 12.4$, $p < 0.001$, 1 df, n = 2438), in contrast to travel within 2m of the formal trail. All other treatments had highly significant reductions in off-trail travel beyond 2m from the formal trail. Fencing had the greatest reduction of off-trail travel among all treatments, to 6.2% (Table 2).

Tukey's HSD and Scheffe grouping statistics were computed to understand treatment levels with similar means. Blazing and coping stones were not significantly different than control conditions in deterring off-trail travel (Table 2). The education, scree wall, and integrated treatments were shown to have similar, improved effects over control conditions. Fencing (including trailside cairns), however, was excluded from this group as the single most effective measure for reducing off-trail travel for excursions both within and beyond 2m from the formal trail.

Park et al. (2008) found that at a popular summit area in Acadia National Park, some site management measures may have a "latent effect" on off-trail behaviors, after hikers continued down the trail beyond the extent of the site management measures. Latent (or carry-over) effects were investigated across the length of the study area for treatments including a continuous site management technique (fencing or scree wall). No significant carryover effect was found for the scree wall treatment ($\chi^2 = 2.174$, $p = 0.140$, 1 df, n = 719), with a near off-trail percentage 4.2%

higher than the control for this section (19.6%). Similarly, no significant carryover effect was found for symbolic fencing ($\chi^2 = 0.147$, $p = 0.701$, 1 df, n = 776), with a near off-trail percentage only 1% lower than the control condition for this section and direction of travel (14.4%).

The number of seconds a visitor was observed to read the educational signage did not have a significant inverse effect on off-trail rates ($\chi^2 = 56.325$, $p = 0.303$, 36 df, n = 518) (Table 3). No clear trend was shown to exist in the relationship between time spent reading the educational signage and the percentage of visitors going off-trail (Figure 4-2). Further analysis showed that near off-trail travel reduction was significant ($\chi^2 = 29.427$, $p = 0.043$, 18 df, n = 518), and that far off trail travel (beyond 2m from the formal trail) was highly significant ($\chi^2 = 35.062$, $p = 0.001$, 36 df, n = 518). Visitors who spent the most time reading the sign were also the most likely to go off-trail subsequently. The data are inconclusive.

"Effective group" ID was procedurally generated for each visitor during the educational message treatment. The ID was assigned based on temporal groupings of people entering the study area (i.e., people hiking near others in time regardless of any social relationship or lack thereof). Visitors entering the study area within 30 seconds of earlier visitors (i.e., within visual proximity of each other) were assigned the same ID. Previous research at Acadia suggested that the presence of others off-trail nearby serves as a releaser cue for a visitor to engage in off-trail behavior. This effect was highly significant ($\chi^2 = 562.8$, $p < 0.001$, 412 df, n = 518) on off-trail behaviors. Since effective IDs were assigned irrespective of social units (e.g., families, groups of friends, or couples), shared IDs across visitors likely mix social units; the extent of this mixing is unknown.

Discussion and Conclusions

Treatment Efficacy

This research effort investigated alternative means to discouraging off-trail traffic through a series of additive experimental trials. As has been suggested by other literature, the trials incorporating more-direct measures tended to be more effective than measures relying primarily on indirect measures (i.e., information/education). One relatively unique approach taken by this research study was to examine the cumulative effects of multiple techniques applied simultaneously, e.g., combining the information/education approach with site management. If management techniques are effective ultimately because they address specific motivations for a given depreciative behavior, it follows that additive techniques targeted to multiple potential motivations should be more effective than individual techniques. These methods were effective at substantially reducing off-trail behavior. However, the most effective method relied almost exclusively upon symbolic fencing. This result suggests that, where intensive resource protection effort is required, application of multiple techniques may be unnecessarily costly where a low symbolic fence will perform even better.

Similarly, it is important to note that visually-continuous site management techniques were the most effective at reducing off-trail behavior rates. Specifically, a low continuous stone scree wall performed better than coping stones made of the same material and spaced at even intervals along the trail. While the coping stones did form a somewhat continuous demarcation of the trail border when viewed from oblique angles normally experienced while hiking, it may be important that the border is present at the very moment a visitor considers walking off-trail (or approaches a location where it is easy to wander off the formal trail unintentionally). While construction of scree walls is certainly more labor and resource intensive than that of coping stone installation, it is considerably more effective, especially in rocky environments like Acadia ridge-top trails where it can potentially be difficult for a visitor to intuit that a given stone is, in fact, a border marker. However, it should be noted that this approach could be potentially visually obtrusive. Because intensive delineation of the trail through extended blazing did not have a strong effect on off-trail behavior rates, it is likely that confusion over what constitutes the formal trail (versus informal side trails running parallel and shortcuts) is a strong driver of off-trail behaviors.

The information/education approach did significantly reduce off-trail behavior from control levels. This approach is popular with managers because it is usually reported to be among the most acceptable of management alternatives to visitors. Gorham Ridge trail is a popular trail accommodating hundreds of visitors a day through a natural community with extremely low recovery rates. In this context, reductions in off-trail behavior may not promote resource recovery and protection. Although the educational signage in this study used multiple techniques validated in the literature for enhancing message effectiveness (attribution, prescriptive injunctive wording, peripheral route to persuasion via the perceived authority of the international Leave No Trace program and NPS logo), the reduction in off-trail behavior achieved in this manner was not sufficient on its own to protect resources. This study demonstrated that combining this information/education signage with direct site management in the form of coping stones was less effective than a continuous scree wall without the signage. Managers should not plan to rely on the effectiveness of the information/education approach at Acadia wherever trailside resources are fragile or already degraded.

Educational signage should be placed in locations that prevent visitors "bunching up" around them and blocking views to the management messages on display. Recorded video data showed that larger groups and visitors standing close to the sign occasionally obstructed it for other, passing recreationists. Recreationists cannot be alerted to types and degrees of resource degradation if they are unable to see the sign, or can easily walk by it at a distance, as is the case with many trailhead signs and bulletin spaces.

Cost Implications

Management intensity must be balanced against cost. Acadia's ridge trails are currently marked by historical rock cairns and blazing. Unfortunately some visitors destroy, alter, or add to these cairns, leading to ongoing maintenance costs. In this situation, continuous site management measures such as low rock scree walls or symbolic fencing may be more desirable than cairns in that they present less of an individualized "target" for depreciative behaviors, and less costly long term (Doucette and Kimball 1990). A well-designed scree wall can fade into the scenery but provide a needed prompt to stay on trail wherever necessary. Replacing the cairns with additional paint blazes (less expensive in the short term), however, is not an effective off-trail behavior deterrent, particularly in settings like Acadia where the formal trail can "disappear" in open bedrock areas and be one among several informal trail options at the far end of the bedrock face. This situation increases the difficulty in successfully remaining on the formal trail.

The companion study to this work suggested a latent effect among some site management treatments (i.e., treatments lowered off-trail behaviors beyond the extent of the actual site management) (Park et al. 2008). However, no similar relationship was found in the backcountry study area for fencing or scree walls. This study suggests that any latent effect may be situation and/or site-specific. However it should be utilized wherever possible, as it represents "free" effects beyond the installed extent of site management measures. One potential application could be utilizing obtrusive effects in sites of maximal degradation, and relying on any latent effect for proximal, marginally degraded areas.

Management Implications

As a result of the insights gained from this and related studies on reducing depreciative behavior on trail systems, the authors suggest an integrated, additive management approach on reducing depreciative behavior on the backcountry trail system at Acadia National Park. Where resource degradation is most intense, e.g., near perceived vista locations along ridgeline trails similar to that of the study area, it is important to adopt a direct, site management approach. This research underscores that information/education-based approaches are not efficacious alone at reducing off-trail travel to sufficient levels. Consequently, low, symbolic fencing should be installed across junctions of the formal trail with informal trails leading to appealing shortcuts or vista sites where resource degradation is a major concern. In other locations where degradation is topographically constrained, vista side trails could be formalized and managed against further resource harm. As trail realignment is a costly measure, it should in this case be used as a last resort. Where resource degradation is still a concern but to a lesser degree than that requiring low symbolic fencing, natural material scree walls should be installed.

This research confirmed the importance of a visually continuous border along the trail to help visitors understand where the formal trail is and is not, as well as providing a gentle reminder cue at any point where the visitor could have the urge to engage in off-trail behavior. The contrast in effects between the blazing treatment and continuous border treatments suggests that continuous prompts to remain on the formal trail address the motivation to go off-trail in this high use backcountry setting. To reinforce this visual reminder at key locations including informal trail junctions, low-profile symbolic prompter signs could be installed. At locations that are actively degrading, larger educational signage could be installed to sensitize visitors to the effect of careless footsteps. When these signs are used, they can be placed close to the trail so that they are easily read in a narrow section so that visitors pass it single file.

Video-Based Data Collection

The researchers would like to note the utility and effectiveness of using a video recorder-based data collection approach. By mounting digital cameras throughout the study area, field staffing needs (aside from the setup needs of each experimental treatment) were reduced to a single technician required to change out the 60 lb. battery and make periodic data backups to DVD. The resolution and placement of the cameras ensured sufficient detail for interpretation of visitor location and behavior, but protected the confidentiality of visitors participating in the study. An added benefit was the ability to recheck observational data through later review of the video footage in the few ambiguous evaluations that arose during the course of data transcription. Perhaps most importantly, though, the video surveillance approach allowed explicit, precise, and reproducible demarcations of on-trail and off-trail locations, a difficulty usually associated with studies of this nature.

A further development of this off-trail zone demarcation technique yielded the sub-zoning of near off-trail and far off-trail behavior zones, which were mapped to potentially differing reasons for going off-trail. Specifically, near off-trail behavior (within 2m of the formal trail) appeared almost always due to a visually unclear edge to the formal trail or the need to get around a large cluster of other visitors blocking the way while standing on the trail. Far off-trail behavior, by contrast, usually was due to visitors intentionally seeking alternate routes (e.g., to explore) or to seek out vistas along the trail.

Further Study

This study did have some limitations and results suggest areas of inquiry for further research. This study examined additive approaches to combining multiple management techniques intended to encourage visitors to stay on the formal trail system. Each experimental trial was analyzed for the sum effect of all the techniques used in that trial. Constraints on staffing and the length of the peak visitor use season prevented the use of a more powerful full factorial design that would allow further insight regarding the relative contributions of individual techniques within each trial. This study also assessed the efficacy of a limited subset of techniques. Additional study is suggested to further advance our understanding of the additive effects of an expanded range of management techniques for a backcountry trail setting, e.g., alternative border materials such as downed logs.

Finally, the empirical observation approach used in this study is useful as an objective measure of visitor behaviors. However, observation tells researchers little about visitor cognitive processes and motivations for undertaking the behaviors that they do. Ideally, qualitative interviews of visitors linked to their observation data would be a powerful means of understanding visitor behaviors on trail networks on a reasoning and thought process level. For example, it would be useful to know why some visitors pause to read a sign carefully and why others walk past without a second glance. Further insights of this nature help to expand our understanding of the efficacy and suitability of management actions designed to keep visitors on-trail. Finally, in evaluating the efficacy of varying management alternatives designed to encourage formal trail use, managers and researchers must also consider the site-specific aesthetic impacts of a given technique or combination of techniques. While some research has been conducted on this effect, relatively little is known about the potential combined aesthetic impacts of multiple additive management techniques. An attitudinal survey research effort could serve to expand the field in this area.

Tables

Table 4-1. Summary of off-trail behavior management techniques included in each treatment.

	Management Actions								
Treatments	Educational Signs	Additional Paint Blazes	Cairns	Coping Stones	Scree Wall	Trailside Fencing	Prompter Signs	# of Actions Included	n
Control (baseline)	No	No	Yes	No	No	No	No	1	1170
Blazing	No	Yes	No	No	No	No	No	1	847
Educational Signs	Yes	Yes	Yes	No	No	No	Yes	4	773
Coping Stones, 6 ft	No	No	Yes	Yes	No	No	No	2	1261
Low Scree Wall	No	No	Yes	No	Yes	No	No	2	686
Symbolic Fencing	No	No	Yes	No	No	Yes	No	2	818
Integrated	Yes	No	Yes	Yes	No	No	Yes	4	1192

Table 4-2. Efficacy of measures designed to encourage visitors to remain on-trail.

Treatment	Percentage Off-Trail Within 2 m (n)[2]	Percentage Off-Trail Beyond 2 m (n)[2]	Total n[1]
Control (baseline)	49.91 (586)[1, a]	22.91 (269)[1, BA]	1174
Blazing	40.50 (343)[2, b]	21.02 (178)[1, CB]	847
Educational Signs	31.56 (244)[3, bc]	13.71 (106)[2, DC]	773
Coping Stones, 6 ft	48.25 (610)[1, ab]	29.19 (369)[3, A]	1264
Low Scree Wall	21.72 (149)[4, d]	13.27 (91)[2, ED]	686
Symbolic Fencing	11.12 (91)[5, e]	6.23 (51)[4, E]	818
Integrated	24.55 (298)[4, cd]	11.78 (143)[2, 4, ED]	1214

1. Harmonic mean n = 918.49; Bonferroni-type correction applied to significance and grouping interpretation.
2. Tukey's HSD groupings as numbered and (conservative Scheffe's groupings as lettered).

Table 4-3. Time spent reading educational signage and the effect on off-trail behavior rates.

Signage Reading Time	On-Trail Percentage (n)	Percentage Off-Trail Within 2 m (n)	Percentage Off-Trail Beyond 2 m (n)	Total
Less than 2 seconds	63.30 (176)	18.34 (51)	18.34 (51)	278
2 to 4 seconds	77.44 (103)	15.03 (20)	7.518 (10)	133
4 to 6 seconds	63.63 (35)	21.81 (12)	14.54 (8)	55
More than 6 seconds	57.69 (30)	23.07 (12)	19.23 (10)	52
Total	66.40 (344)	18.33 (95)	15.25 (79)	518

Note: data represent only uphill travelers within the educational signage treatment.

Figures

Figure 4-1. Educational signage posted at each end of the trail study area for some treatments.
Note: The small trailside prompter sign is positioned at center background, placed at intersection of formal and informal trails (inset).

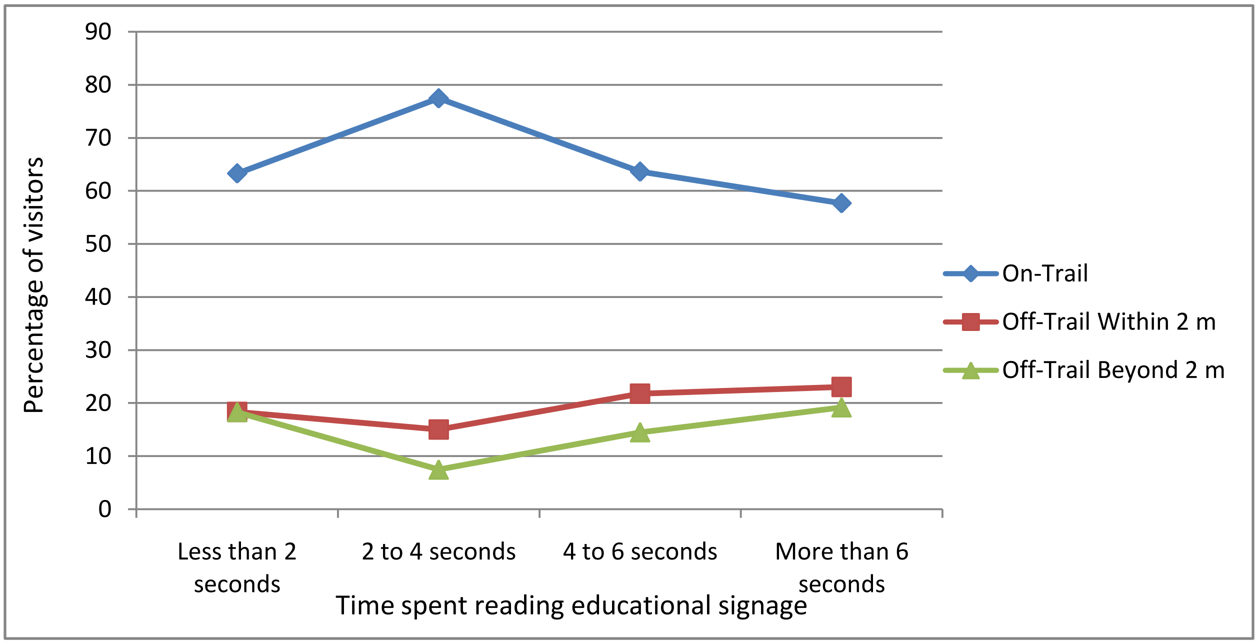

Figure 4-2. Time spent reading educational signage and the effect on off-trail behavior rates.

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Appendices

Appendix A – Cross Sectional Area Measurement Protocols

Acadia National Park Field Manual
(Developed by Dr. Jeff Marion, USGS)

Description of Procedures

This manual describes standardized procedures for conducting an assessment of resource conditions on recreation trails. The principal objective of these procedures is to document and monitor changes in trail conditions following construction. Their design relies on a sampling approach to characterize trail conditions from measurements taken at transects located every 500 feet (152 meters) along randomly selected trail segments. Distances are measured with a measuring wheel. Measurements are conducted at sample points to document the trail's width, depth, substrate, slope, alignment and other characteristics. These procedures take approximately three minutes to apply at each sample point. Data is summarized through statistical analyses to characterize resource conditions for each trail segment and for the entire trail system. During future assessments it is not necessary to relocate the same sample points for repeat measures. Survey work should be conducted during the middle or end of the primary use season. Subsequent surveys should be conducted at approximately the same time of year.

Materials

This manual on waterproof paper　　Random # table

Topographic and driving maps

Clipboard w/compartment for forms　　Pencils　　Tape measure (12ft)

Field forms (two types) - some on waterproof paper Measuring wheel Compass

20 ft 1/16th inch braided nylon string with 12 sliding beads Tent stakes (3)

Clinometer

Point Sampling Procedures

Trail Segments: During the description of amount and type of use (indicators 5 & 6 below) be sure that the use characteristics are relatively uniform over the entire trail segment. Sampled trails may have substantial changes in the type or amount of use over their length. For example, one portion of a trail may allow horse use or a trail may join the study trail, significantly altering use levels. In these instances where substantial changes in the type and/or amount of use occur, the trail should be split in two or more segments and assigned separate names and forms, upon which the differences in use can be described. This practice will facilitate the subsequent characterization of trail use and statistical analyses.

Also collect and record any other information that is known about the trail's history, such as original construction, past uses, type and amount of maintenance, history of use, etc.

1) Trail Segment Code: Record a unique trail segment code (can be added later).

2) Trail Name: Record the trail segment name(s) and describe the segment begin and end points.

3) Surveyors: Record initials for the names of the rail survey crew.

4) Date: Record the date (mm/dd/yr) the trail was surveyed

5) Use Level (UL): Record an estimate of the amount of use the trail receives, relative to all trails in the park, from the most knowledgeable park staff member: High, Medium, Low. Work with them to quantify these use levels on an annual basis (e.g., low use, < 100 users/wk for the 12 wk use season, < 30 users/wk for the 20 wk shoulder season, < 10 users/wk for the 20 wk off-season = < 2000 users/yr).

6) Use Type (UT): Record estimates for the types of use the trail receives (including any illegal uses) using percentages that sum to 100%. These should be provided by the most knowledgeable park staff member. Categories include: Hiking, Horseback, Vehicle, Bike, Other (specify).

Starting/Ending Point: Record a brief description of the starting and ending point of the trail survey. Try to choose identifiable locations like intersections with other trails, roads, or permanent trailhead signs.

Measuring Wheel Procedures: At the trail segment starting point, use a random number table to select a random number from 0 to 500. Record this number on the first row of the form. This will be the first sample point, from which all subsequent sample points will be located in 500 foot intervals. This procedure ensures that all points along the trail segment have an equal opportunity of being selected. Once you get to the first sample point, reset the wheel counter and use it to stop at 500 foot intervals thereafter.

Push the measuring wheel along the middle of the tread so that it does not bounce or skip in rough terrain. Lift the wheel over logs and larger rocks, adding distance manually where necessary to account for horizontal distances. Your objective is to accurately measure the distance of the primary (most heavily used) trail tread. Monitor the wheel counter closely and stop every 500 feet to conduct the sampling point measures. If you go over this distance, you can back the wheel up to the correct distance. If the wheel doesn't allow you to take distance off the counter then stop immediately and conduct your sampling at that point, recording the actual distance from the wheel, not the "missed" distance.

If an indicator cannot be assessed, e.g., is "Not Applicable" code the data as -9, code missing data as -1.

Rejection of a sample point: Given the survey's objective there will be rare occasions when you may need to reject a sampling point due to the presence of: 1) bedrock or cobble stone areas that lack defined trail boundaries, and 2) uncharacteristic settings, like tree fall obstructions, trail intersections, road-crossings, stream-crossings, bridges and other odd uncommon situations. The data collected at sample points should be "representative" of the 250 foot sections of trail on either side of the sample point. Do not relocate a point to avoid longer or common sections of bog bridging, turnpiking, or other trail tread improvements. Use your judgment but be conservative when deciding to relocate a sample point. The point should be relocated by moving forward along the trail an additional 30 feet, this removes the bias of subjectively selecting a point. If the new point is still problematic then add another 30 feet, and so on. Record the actual distance of the substituted sample point and then push the wheel to the next sample point using the original 500 foot intervals.

7) Distance: In the first column record the measuring wheel distance in feet from the beginning of the trail segment to the sample point.

8) Informal Trails (IT): Sum and record your tallies of informal or "visitor-created" trails that intersected with the survey trail since the last sample point. This indicator is intended to provide an approximation of the extensiveness of unofficial, visitor-created trails associated with survey trail. Do not count formal trails, roads of any type, extremely faint trails, trails <10 ft long, or trails that have been effectively blocked off by managers. Informal trails are trails that visitors have created to access streams, scenic attraction features, camping areas, or other features, to cut switchbacks, to avoid mud-holes, rutted treads, steep obstacles, or downed trees, or that simply parallel the main trail. Count both ends of any informal trails ≥10 feet long that loop out and return to or parallel the survey trail. Include any distinct animal or game trails as these are generally indistinguishable from human trails and their true origin is likely unknown.

9) Tread Width (TW): From the sample point, extend a line transect in both directions perpendicular to the trail tread. Identify the endpoints of this trail tread transect as the most pronounced outer boundary of visually obvious human disturbance created by trail use (not trail maintenance like vegetation clearing). These boundaries are defined as pronounced trampling-related changes in ground vegetation height (trampled vs. untrampled), cover, composition, or, when vegetation cover is reduced or absent, changes in organic litter (intact vs. pulverized) (see photo illustrations in Figure 1). The objective is to define the trail tread that receives the majority (>95%) of traffic, selecting the most visually obvious outer boundary that can be most consistently identified by you and future trail surveyors. Include secondary treads (see #9) within the transect only when they are not differentiated from the main tread by strips of less disturbed (taller) vegetation or organic litter (see the tread boundary description).

Also pay close attention to selecting boundary points that reflect the extent of soil loss representative for this location along the trail. Soil loss measures will be taken from a line stretched between the endpoints you select so the line should be unobstructed. Organic litter or small rocks that obstructs the line can be removed but large rock or root obstructions will necessitate moving the line forward along the trail in one foot increments until you reach a location where the line is unobstructed. Temporarily place tent stakes at the boundary points and then step back to verify their horizontal and vertical placement as projected along the trail in the vicinity of the sample point.

Measure and record the length of the transect (tread width) to the nearest inch (don't record feet and inches).

10) Maximum Incision, Current Tread (MIC): Stretch the nylon string tightly between the two tent stake pins that define the tread boundaries - any bowing in the middle will bias your measurements. Position the string so that it can be used as a datum to measure tread incision caused by soil erosion and/or compaction . Measure the maximum incision (nearest 1/4 inch: record .25, .5, .75) from the string to the deepest portion of the trail tread. Measure to the surface of the tread's substrate, not the tops of rocks or the surface of mud puddles. Your objective is to record a measure that reflects the maximum amount of soil loss along the transect within the tread boundaries. See Figure 2, noting differences in MIC measures for side-hill vs. non-side-hill trails.

11) Cross-Sectional Area: On the Cross Sectional Area form, record the distance from the measuring wheel. Record a 0 in the Area column and skip this procedure if the maximum incision is <1 inch. Otherwise complete the following:

Starting at the left tread boundary, position beads along the nylon string so that they are above tread surface locations that, if connected with straight lines, would accurately characterize the tread cross-section (see figure at right).

Measure and record the distance to each bead from the left stake. It's most efficient to record these distances in the field and calcuate intervals (I_1 to I_n) later. Record distances to the nearest 1/4 inch (e.g., .25, .5, .75). Record transect and interval data in pairs on the field form.

Measure (nearest 1/4 inch) vertical perpendicular transects from the line down to the tread surface (T_1 to T_n) beginning with the 1st bead to the right of the left tent stake (T_1) and ending with the right-hand tent stake ($T_n = 0$). Note that vertical transects should be oriented at right angles to the string, they will not be plumb (perpendicular to the ground) in instances where the string is not level.

Compute and sum cross-sectional area with the following formula (contact author for a computer program):

Area = (left transect + right transect) x Interval x .5 for each row and summed for the total area of soil loss. Note that the left transect for T_1 is 0 and T_n is 0.

12-21) <u>Tread Condition Characteristics:</u> Along the trail tread width transect, estimate to the nearest 10% (5% where necessary) the aggregate lineal length occupied by any of the mutually exclusive tread surface categories listed below. Be sure that your estimates sum to 100%.

S-Soil:	All soil types including sand and organic soils, excluding organic litter unless it is highly pulverized and occurs in a thin layer or smaller patches over bare soil.
L-Litter:	Surface organic matter including intact or partially pulverized leaves, needles, or twigs that mostly or entirely cover the tread substrate.
V-Vegetation:	Live vegetative cover including herbs, grasses, mosses rooted within the tread boundaries. Ignore vegetation hanging in from the sides.
R-Rock:	Naturally-occurring rock (bedrock, boulders, rocks, cobble, or natural gravel). If rock or native gravel is embedded in the tread soil estimate the percentage of each and record separately.
M-Mud:	Seasonal or permanently wet and muddy soils that show imbedded foot or hoof prints from previous or current use (omit temporary mud created by a very recent rain). The objective is to include only transect segments that are frequently muddy enough to divert trail users around problem.
G-Gravel:	Human-placed (imported) gravel.
RT-Roots:	Exposed tree or shrub roots.
W-Water:	Portions of mud-holes with water or water from intercepted seeps or springs.
WO-Wood:	Human-placed wood (water bars, bog bridging, cribbing).
O-Other:	Specify.

22) **Trail Grade (TG):** The two field staff should position themselves at the sample point and 10 feet upslope along the trail. A clinometer is used to determine the grade (% slope) by sighting and aligning the horizontal line inside the clinometer with a spot on the opposite person at the same height as the first person's eyes. Note the percent grade (right-side scale in clinometer viewfinder) and record .

23) **<u>Trail Alignment (TA):</u>** Assess the trail's alignment angle to the prevailing land-form in the vicinity of the sample point. Use a compass and sight along the trail in the vicinity of the sample point, record the compass bearing on the left side of the column (it doesn't matter which direction along the trail you sight). Next face directly downslope, take and record another compass bearing (aspect). The trail's alignment angle can be computed by these two bearings (done by computer).

24) **<u>Side-hill Construction (SH):</u>** Was side-hill construction (cut-and-fill) work used to construct the trail at the sample point? Yes (Y), No (N), Unsure (U).

25) **<u>Tread Drainage Feature (TD):</u>** In 25-foot increments up to 75 feet, estimate the distance to any reasonably effective human-constructed tread drainage feature located in an up-slope trail direction from the sample point. Record a 100 if no features are present within 75 feet. Tread drainage features could include water bars (wood or rock), drainage dips, grade dips, etc. constructed to move water off the trail tread (do not consider tread out-sloping).

26) **<u>Water Drainage (WD):</u>** During a medium-sized rain storm, about how much of the water on the trail up-slope within 10 feet from the sample point would tend to flow **off** the tread: 1) 0%, 2) 25%, 3) 50%, 3) 75%, or 4) 100%. This could be due to a natural or human-constructed tread drainage feature or to tread out-sloping.

27) **<u>Trail Position (TP):</u>** Use the descriptions below to determine the trail position of the sampling point. Record the corresponding letter code in the TP column.

V - Valley Bottom: The transect is located within a flatter valley bottom setting within 60 vertical feet (three 20ft topo lines) from a stream or river.

R - Ridge Top: The transect is located within a flatter plateau or ridge-top position.

M - Midslope: All other mid-slope positions.

28) **<u>Soil Texture (TX):</u>** Follow the field method described by Foth (1990) to determine the soil texture of the soils in the vicinity of the sample point. Soil texture should not vary substantially along most trails. This assessment should be done at the start of the trail (have some water to use and rinse your hands with). Check the texture without wetting at the sample points and repeat the full method if it appears to have changed.

a) Moisten a sample of soil the size of a golf ball and work it until it's uniformly moist; squeeze it out between the thumb and forefinger to try to form a ribbon.

b) First Decision: If the moist soil is:

* Extremely sticky and stiff, it is a clay.

* Sticky and stiff to squeeze, it is a clay loam.

* Soft, easy to squeeze, and only slightly sticky, it is a loam.

c) Second decision: Add an adjective to refine the description.

If the soil feels:

* Very smooth, it is silt or silty (# 3, 6, or 9).

* Somewhat gritty, use no adjective (#2, 5, or 8).

* Very, very gritty, it is sandy (# 1, 4, or 7).

d) Combine your (b) and (c) determinations to identify and record the proper classification on the form:

1 - sandy clay
2 - clay
3 - silty clay
4 - sandy clay loam
5 - clay loam
6 - silty clay loam
7 - sandy loam
8 - loam
9 - silt loam
10 - organic soil

Collect all equipment and move on to the next sample point. **Be sure to count and tally informal trails and record information on indicators 30 & 31 as you proceed to the next sample point.** These indicators are assessed continuously as pre-defined trail tread problems and when found, surveyors record begin and end distances (from the start of the survey) on the Problem Assessment Form. **Note: after data entry and before analysis the data for these indicators need to be corrected to add in the 1st randomly selected interval distance so that location data are accurate. In particular, examine any indicators that may begin before and end after the first sample point.**

29) <u>**Muddy Soil (MS):**</u> Sections of tread (≥10 ft) with seasonal or permanently wet and muddy soils that show imbedded foot or hoof prints (≥½ inch). Omit temporary muddiness created by a recent rain. This should generally include any longer mud-holes or treads with running water. The objective is to include only tread segments that are frequently wet or muddy enough to divert trail users around the problem, often leading to an expansion of trail width.

30) **Soil Erosion (SE):** Sections of tread (≥10 ft) with soil erosion exceeding 5 inches in depth within current tread boundaries. Record SE1 for soil loss 5-10 in., SE2 for 10.1-15 in. and SE3for 15.1-20 in.

Figure 1. Photographs illustrating different types of boundary determinations. Trail tread boundaries are defined as the most pronounced outer boundary of visually obvious human disturbance created by trail use (not trail maintenance like vegetation clearing). These boundaries are defined as pronounced changes in ground vegetation height (trampled vs. untrampled), cover, composition, or, when vegetation cover is reduced or absent, as pronounced changes in organic litter (intact vs. pulverized). The objective is to define the trail tread that receives the majority (>80%) of traffic, selecting the most visually obvious boundary that can be most consistently identified by you and future trail surveyors.

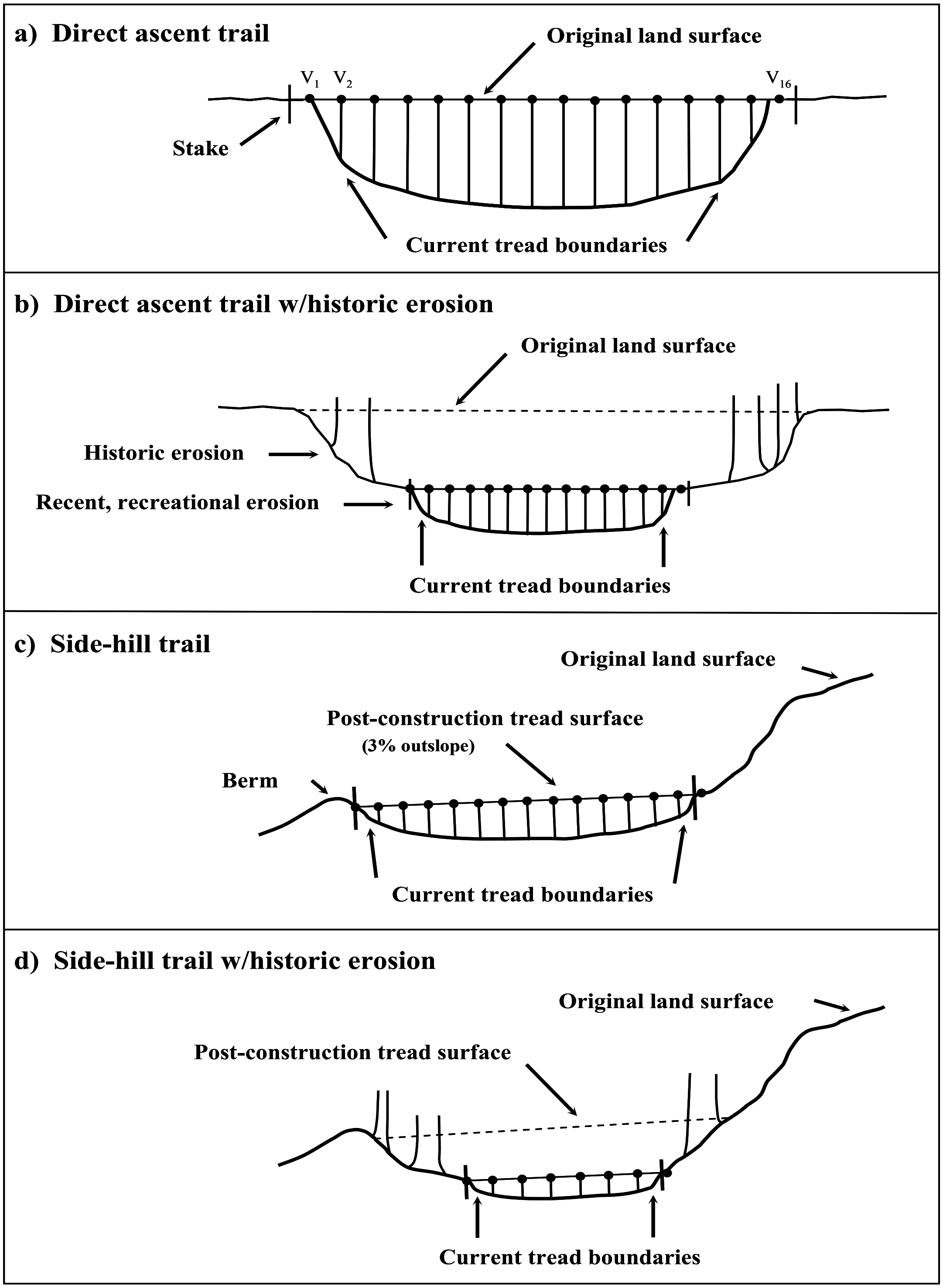


Figure 2. Diagrams illustrating alternative tread incision measurements in terrain where cut and fill work was not performed during tread construction (a-c) and in terrain where sidehill construction involved the excavation of substrate to create a tread surface (d-f).

Point Sampling Form

Trail Segment Code _________ **Trail Name** ____ **Surveyors**

Date __________ **Use Level** ________ **Use Type(s):** Horse% Hiker% Vehicle% ATV% Bike%

Starting/Ending Point:

Dist	IT	ST	TW	MIC	Tread Substrate Characteristics	TG	TA	SH	TD	WD	TP	TX
					0 10 20 30 40 50 60 70 80 90 100							

Dist = Wheel Distance
IT=Informal Trails
ST=Secondary Treads
TW=Tread Width
MIC=Max. Incision, Current Tread

S=Soil
L=Litter
V=Vegetation
R=Rock
M=Mud

G=Gravel
RT=Roots
W=Water
WO=Wood, human placed
O=Other (Specify)

TG=Trail Grade
TA=Alignment (Trail° / Landform°)
SH=Side-Hill construction (Y, N, U)
TD=Tread Drainage feature (25, 50, 75, or 100)
WD=Water Drainage (0%, 25%, 50%, 75%, 100%)
TP=Trail Posit. (Valley=V, Mid-slope=M, Ridge-top=R)
TX=Soil Texture (1-10)

Problem Assessment Form

Cross Sectional Area Form

Trail Segment Code ________ Trail Name

Muddy Soil		Soil Erosion		Cross Sectional Area			Cross Sectional Area			Cross Sectional Area		
Begin Dist	End Dist	Begin Dist	End Dist	Transect (in)	Inter-val (in)	Area	Transect (in)	Inter-val (in)	Area	Transect (in)	Inter-val (in)	Area

Zion National Park Field Manual

(Developed by Dr. Jeff Marion)

Field staff: Nate Olive and Sarah Janes

Research Objectives:

1) Select prospective trail condition indicators and develop objective and efficient monitoring protocols for their assessment.

2) Experimentally apply and refine field procedures for three types of trail survey methods: point sampling, problem assessment, and transect.

3) Develop some baseline data to characterize resource conditions on designated trails in the Primitive Zone and visitor-created trails in the Pristine Zone.

4) Analyze and present data in format's suitable to assist managers in selecting trail condition indicator standards.

CSA Experiment:

The objective of this work is to produce a data set that can be analyzed to evaluate the accuracy and efficiency (time) of the new variable transect CSA procedures. This will be done by comparing the variable transect CSA measures to measures derived from "fixed" transects. The most accurate, or "true" value for the CSA will be derived from the fixed method with transects taken at 1/10 foot intervals. By sampling the fixed transects we can also show comparisons between the variable transect CSA method and the fixed method with transects every 1/10th foot, ¼ foot, ½ foot, etc. By recording the time required to take one transect measure we can also compare efficiency.

Study locations will be purposively selected based on the extent of erosion (high, intermediate, low) and complexity of the cross section (high, low). It would be good to get a minimum of 3 replicates within each cell of this matrix (a total of 18 study transects). I think a good area to do these would be along the West Rim Trail, there was high erosion nearest the main Zion valley. Try to stick to trails of a roughly uniform width. With respect to erosion, I suspect that low erosion would be in the 1-2 inch MIC range, intermediate would be in the 4-5 inch range and high would be in the 7+ inch range. With respect to complexity of the cross section, high would be a cross section that is complex – requiring a large number of beads to account for changes in the shape of the tread profile due to roots, rocks, or differential rutting. For example, at Acadia NP many of the trails had extensive exposure of tree roots or rocks in the tread that caused me to more than double the time and number of beads required to accurately characterize the tread's profile. Low would be a more simple shape, such as that depicted in the figure on page 3 of the manual. If you are unable to locate a sufficient number of high complexity transects you can place rocks of various sizes under the transect line to simulate this issue. For statistical testing 3 replicates would be nice, five would be even better if it turns out that this experiment goes quickly (I'm expecting about 1 day's effort for this).

At the selected transect locations start by selecting the trail boundaries and inserting the tent pegs, then stretching the fiberglass tape measure so you can see the feet (tenths) side. The tent pegs need to be in secure locations so they won't move during the following procedures and so you can stretch the tape measure tightly (move the transect if necessary). The larger steel nail tent pegs I enclosed might be better for this procedure. Record the time it takes you to do this. Next use the small tape measure to record transect lengths every $1/10^{th}$ foot all the way across from tent peg to tent peg. Measure from the tread surface to the bottom of the tape measure. Be careful to ensure that your vertical transect measures are perpendicular to the fiberglass tape measure stretched between the tent pegs (note: the stretched tape measure may not be "level" so we are not using a plumb bob type measure for our verticals). It is critical because of the calculations we will be using that you “eye-ball” the vertical transects to ensure they are oriented perpendicular to the horizontal tape measure. Record the time it takes to do these measures and divide by the number of transects to get an average time/transect (probably just need to do this on a few of the transects, not all).

Next place the string from peg to peg, ensuring that it is at the exact same height as the tape measure (and same sag if that’s an unavoidable problem). If a tent peg comes out or moves up/down you will need to start the entire procedure over again! The whole point is to compare the two methods so the string needs to be at the same height as the fiberglass tape measure. Next begin a timer and position the beads as you normally would (do this carefully, however!!!). Record the time needed for the bead positioning - do this on all transects as the time will vary for high vs. low erosion and high vs. low complexity. Next record the vertical transect measures for each bead as you normally do.

Big South Fork National River and Recreation Area
(Developed by Dr. Jeff Marion)

Description of Procedures

This manual describes standardized procedures for conducting an assessment of resource conditions on recreation trails. The principal objective of these procedures is to document and monitor changes in trail conditions following construction. Their design relies on a sampling approach to characterize trail conditions from measurements taken at transects located every 500 feet (152 meters) along randomly selected trail segments. Distances are measured with a measuring wheel. Measurements are conducted at sample points to document the trail's width, depth, substrate, slope, alignment and other characteristics. These procedures take between 3 to 6 minutes to apply at each sample point. Data is summarized through statistical analyses to characterize resource conditions for each trail segment and for the entire trail system. During future assessments it is not necessary to relocate the same sample points for repeat measures. Survey work should be conducted during the middle or end of the primary use season during the growing season. Subsequent surveys should be conducted at approximately the same time of year.

Materials

This manual on waterproof paper
Field forms (both types) - some on waterproof paper

Clipboard w/compartment for forms
Measuring wheel
Topographic and driving maps

Tape measure (12ft)
Pencils
Tent stakes (2)
Clinometer
Compass

20 ft 1/16th inch braided nylon string with 12 beads (or twist-ties) attached
Random # table

Point Sampling Procedures

Trail Segments: During the description of amount and type of use (indicators 5 & 6 below) be sure that the use characteristics are relatively uniform over the entire trail segment. Most of the study trails have multiple uses, though uses are regulated on some trails. For example, a gate in the middle of a study segment restricting vehicle use beyond it or a sign prohibiting horse use, can substantially affect visitation and impact. Even when use types are not regulated the study trail may intersect with another route that diverts one of the user groups. In such instances where substantial changes in the type and/or amount of use occur, the trail should be split in two segments and assigned separate names and forms, upon which the differences in use can be described. This practice will facilitate subsequent statistical summaries and analyses.

Also collect and record any other information that is known about the trail's history, such as original construction, past uses, type and amount of maintenance, history of use, etc.

1) Trail Segment Code: Record a unique trail segment code (can be added later).

2) Trail Name: Record the trail segment name(s) and describe the segment begin and end points.

3) Surveyors: Record initials for the names of the rail survey crew.

4) Date: Record the date (mm/dd/yr) the trail was surveyed.

5) Use Level (UL): Record an estimate of the amount of use the trail receives, relative to all trails in the park, from the most knowledgeable park staff member: High, Medium, Low. Work with them to quantify these use levels on an annual basis (e.g., low use, < 100 users/wk for the 12 wk use season, < 30 users/wk for the 20 wk shoulder season, < 10 users/wk for the 20 wk off-season = < 2000 users/yr).

6) Use Type (UT): Record estimates for the types of use the trail receives (including any illegal uses) using percentages that sum to 100%. These should be provided by the most knowledgeable

park staff member. Categories include: Hiking, Horseback, Vehicle, ATV, Bike, Wagon, Other (specify).

Starting/Ending Point: Record a brief description of the starting and ending point of the trail survey. Try to choose identifiable locations like intersections with other trails, roads, or permanent trailhead signs.

Measuring Wheel Procedures: At the trail segment starting point, use a random number table to select a random number from 0 to 500. Record this number on the first row of the form. This will be the first sample point, from which all subsequent sample points will be located in 500 foot intervals. This procedure ensures that all points along the trail segment have an equal opportunity of being selected. Once you get to the first sample point, reset the wheel counter and use it to stop at 500 foot intervals thereafter.

Push the measuring wheel along the middle of the tread so that it does not bounce or skip in rough terrain. Lift the wheel over logs and larger rocks, adding distance manually where necessary to account for horizontal distances. Your objective is to accurately measure the distance of the primary (most heavily used) trail tread. Monitor the wheel counter and stop every 500 feet to conduct the sampling point measures. If you go over this distance, you can back the wheel up to the correct distance. If the wheel doesn't allow you to take distance off the counter then stop immediately and conduct your sampling at that point, recording the actual distance from the wheel, not the "missed" distance.

If an indicator cannot be assessed, e.g., is "Not Applicable" code the data as -9, code missing data as -1.

Rejection of a sample point: Given the survey's objective there will be rare occasions when you may need to reject a sampling point due to the presence of boulders, tree falls, trail intersections, road-crossings, stream-crossings, bridges or other odd "uncharacteristic" situations. The data collected at sample points should be "representative" of the 250 foot sections of trail on either side of the sample point. Do not relocate a point to avoid longer or common sections of bog bridging, turnpiking, or other trail tread improvements. Use your judgment but be conservative when deciding to relocate a sample point. The point should be relocated by moving forward along the trail an additional 30 feet, this removes the bias of subjectively selecting a point. If the new point is still problematic then add another 30 feet, and so on.

7) <u>Distance:</u> In the first column record the measuring wheel distance in feet from the beginning of the trail segment to the sample point.

8) <u>Informal Trails (IT):</u> Sum and record your tallies of informal or "visitor-created" trails that intersected with the survey trail since the last sample point. Do not count formal trails or roads of any type, or extremely faint trails or trails that have been blocked off by managers. Informal trails are trails that visitors have created to access streams, scenic attraction features, camping areas, or other features, to cut switchbacks, go around mud-holes or downed trees, or that simply parallel the main trail. Count both ends of any informal trails longer than 20 feet that loop out and return to or parallel the survey trail. Include any distinct animal or game trails as these are often indistinguishable from human trails and their true origin is likely unknown. This indicator is intended to provide an approximation of the extensiveness of unofficial, visitor-created trails associated with survey trail.

9) <u>Secondary Treads (ST):</u> Count the number of trails that parallel the main tread at the sample point. Count all treads regardless of their length. *Do not count the main tread*.

10) <u>Tread Width (TW):</u> From the sample point, extend a line transect in both directions perpendicular to the trail tread. Identify the endpoints of this trail tread transect as the most pronounced outer boundary of visually obvious human disturbance created by trail use (not trail maintenance like vegetation clearing). These boundaries are defined as pronounced changes in ground vegetation height (trampled vs. untrampled), cover, composition, or, when vegetation cover is reduced or absent, as pronounced changes in organic litter (intact vs. pulverized) (see photo illustrations in Figure 1). The objective is to define the trail tread that receives the majority (>95%) of traffic, selecting the most visually obvious outer boundary that can be most consistently identified by you and future trail surveyors. Include any secondary treads (see #9) within the transect unless there are undisturbed areas between

treads (as defined by the tread boundary definition). In this latter case, establish the transect and conduct measurements for the primary tread. Temporarily place tent stakes at the boundary points. Note: incision and cross-sectional area measures will be taken from this line so it should be unobstructed. If raised up by soil or litter then push down the obstructing materials. If pushed up substantially by rocks or roots then move the line forward along the trail in one foot increments until you reach a location where the line is unobstructed. Measure and record the length of the transect (the tread width) to the nearest inch (don't record feet and inches).

11) <u>Maximum Incision, Current Tread (MIC):</u> Stretch the nylon string tightly between the two tent stake pins that define the tread boundaries - any bowing in the middle will bias your measurements. Position the string so that it can be used as a datum to measure tread incision caused by soil erosion and/or compaction . Measure the maximum incision (nearest 1/4 inch: record .25, .5, .75) from the string to the deepest portion of the trail tread. Measure to the surface of the tread's substrate, not the tops of rocks or the surface of mud puddles. Your objective is to record a measure that reflects the maximum amount of soil loss along the transect within the tread boundaries. See Figure 2, noting differences in MIC measures for side-hill vs. non-side-hill trails.

12) <u>Cross-Sectional Area:</u> On the Cross Sectional Area form, record the distance from the measuring wheel. Record a 0 in the Area column and skip this procedure if the maximum incision is ≤1 inch. Otherwise complete the following:

Starting at the left tread boundary, position beads (or twist ties) along the nylon string so that they are above tread surface locations that, if connected with straight lines, would accurately characterize the tread cross-section (see figure at right).

Measure and record the distance to each bead from the left stake. It's most efficient to record these distances in the field and calcuate intervals (I_1 to I_n) with a spreadsheet. (Note: if measuring is done as you position the beads you may be able to place them at whole-inch intervals, otherwise record to the nearest half inch.)

Measure (nearest 1/4 inch: record .25, .5, .75) each vertical transect from the line down to the tread surface (T_1 to T_n) beginning with the left tent stake ($T_1 = 0$) and ending with the other tent stake ($T_n = 0$).

Compute and sum cross-sectional area with the following formula (use a spreadsheet): Area = (Transect 1 + Transect 2) x Interval x .5 for each row and summed for the total area of soil loss.

13-22) Tread Condition Characteristics: Along the trail tread width transect, estimate to the nearest 10% (5% where necessary) the aggregate lineal length occupied by any of the mutually exclusive tread surface categories listed below. Be sure that your estimates sum to 100%.

S-Soil:	All soil types including sand and organic soils, excluding organic litter unless it is highly pulverized and occurs in a thin layer or smaller patches over bare soil.
L-Litter:	Surface organic matter including intact or partially pulverized leaves, needles, or twigs that mostly or entirely cover the tread substrate.
V-Vegetation:	Live vegetative cover including herbs, grasses, mosses rooted within the tread boundaries. Ignore vegetation hanging in from the sides.
R-Rock:	Naturally-occurring rock (bedrock, boulders, rocks, cobble, or natural gravel). If rock or native gravel is embedded in the tread soil estimate the percentage of each and record separately.
M-Mud:	Seasonal or permanently wet and muddy soils that show imbedded foot or hoof prints from previous or current use (omit temporary mud created by a very recent rain). The objective is to include only transect segments that are frequently muddy enough to divert trail users around problem.
G-Gravel:	Human-placed (imported) gravel.
RT-Roots:	Exposed tree or shrub roots.
W-Water:	Portions of mud-holes with water or water from intercepted seeps or springs.
WO-Wood:	Human-placed wood (water bars, bog bridging, cribbing).
O-Other:	Specify.

23) Trail Grade (TG): The two field staff should position themselves at the sample point and 10 feet upslope along the trail. A clinometer is used to determine the grade (% slope) by sighting and aligning the horizontal line inside the clinometer with a spot on the opposite person at the same height as the first person's eyes. Note the percent grade (right-side scale in clinometer viewfinder) and record .

24) Trail Alignment (TA): Assess the trail's alignment angle to the prevailing land-form in the vicinity of the sample point. Use a compass and sight along the trail in the vicinity of the sample point, record the compass bearing on the left side of the column (it doesn't matter which direction along

the trail you sight). Next face directly downslope, take and record another compass bearing (aspect). The trail's alignment angle can be computed by these two bearings (done by computer).

25) Side-hill Construction (SH): Was side-hill construction (cut-and-fill) work used to construct the trail at the sample point? Yes (Y), No (N), Unsure (U).

26) Tread Drainage Feature (TD): In 25-foot increments up to 75 feet, estimate the distance to any reasonably effective human-constructed tread drainage feature located in an up-slope trail direction from the sample point. Record a 100 if no features are present within 75 feet. Tread drainage features could include water bars (wood or rock), drainage dips, grade dips, etc. constructed to move water off the trail tread (do not consider tread out-sloping).

27) Water Drainage (WD): During a medium-sized rain storm, about how much of the water on the trail up-slope within 10 feet from the sample point would tend to flow off the tread: 1) 0%, 2) 25%, 3) 50%, 3) 75%, or 4) 100%. This could be due to a natural or human-constructed tread drainage feature or to tread out-sloping.

28) Trail Position (TP): Use the descriptions below to determine the trail position of the sampling point. Record the corresponding letter code in the TP column.

V - Valley Bottom: The transect is located within a flatter valley bottom setting within 60 vertical feet (three 20ft topo lines) from a stream or river.

R - Ridge Top: The transect is located within a flatter plateau or ridge-top position.

M - Midslope: All other mid-slope positions.

29) Soil Texture (TX): Follow the field method described by Foth (1990) to determine the soil texture of the soils in the vicinity of the sample point. Soil texture should not vary substantially along most trails. This assessment should be done at the start of the trail (have some water to use and rinse your hands with). Check the texture without wetting at the sample points and repeat the full method if it appears to have changed.

a) Moisten a sample of soil the size of a golf ball and work it until it's uniformly moist; squeeze it out between the thumb and forefinger to try to form a ribbon.

b) First Decision: If the moist soil is:

* Extremely sticky and stiff, it is a clay.

* Sticky and stiff to squeeze, it is a clay loam.

* Soft, easy to squeeze, and only slightly sticky, it is a loam.

c) Second decision: Add an adjective to refine the description.

If the soil feels:

* Very smooth, it is silt or silty (# 3, 6, or 9).

* Somewhat gritty, use no adjective (#2, 5, or 8).

* Very, very gritty, it is sandy (# 1, 4, or 7).

d) Combine your (b) and (c) determinations to identify and record the proper classification on the form:

1 - sandy clay	6 - silty clay loam
2 - clay	7 - sandy loam
3 - silty clay	8 - loam
4 - sandy clay loam	9 - silt loam
5 - clay loam	10 - organic soil

Collect all equipment and move on to the next sample point. Be sure to count and tally informal trails and record information on indicators 30 & 31 as you proceed to the next sample point. These indicators are assessed continuously as pre-defined trail tread problems and when found, surveyors record begin and end distances (from the start of the survey) on the Problem Assessment Form. Note: after data entry and before analysis the data for these indicators need to be corrected to add in the 1st randomly selected interval distance so that location data is accurate. In particular, examine any indicators that may begin before and end after the first sample point.

30) Muddy Soil (MS): Sections of tread (≥10 ft) with seasonal or permanently wet and muddy soils that show imbedded foot or hoof prints (≥½ inch). Omit temporary muddiness created by a recent rain. This should generally include any longer mud-holes or treads with running water. The objective is to include only tread segments that are frequently wet or muddy enough to divert trail users around the problem, often leading to an expansion of trail width.

31) Soil Erosion (SE): Sections of tread (≥10 ft) with soil erosion exceeding 5 inches in depth within current tread boundaries.

Point Sampling Form

Trail Segment Code ________ **Trail Name** ____ **Surveyors**

Date __________ **Use Level** _______ **Use Type(s):** Horse% Hiker% Vehicle% ATV% Bike% Wagon%

Starting/Ending Point:

Dist	IT	ST	TW	MIC	Tread Substrate Characteristics	TG	TA	SH	TD	WD	TP	TX
					0 10 20 30 40 50 60 70 80 90 100							

Dist = Wheel Distance
IT=Informal Trails
ST=Secondary Treads
TW=Tread Width
MIC=Max. Incision, Current Tread

S=Soil
L=Litter
V=Vegetation
R=Rock
M=Mud

G=Gravel
RT=Roots
W=Water
WO=Wood, human placed
O=Other (Specify)

TG=Trail Grade
TA=Alignment (Trail° / Landform°)
SH=Side-Hill construction (Y, N, U)
TD=Tread Drainage feature (25, 50, 75, or 100)
WD=Water Drainage (0%, 25%, 50%, 75%, 100%)
TP=Trail Posit. (Valley=V, Mid-slope=M, Ridge-top=R)
TX=Soil Texture (1-10)

Problem Assessment Form **Cross Sectional Area Form**

Trail Segment Code ________ Trail Name

Muddy Soil		Soil Erosion		Cross Sectional Area			Cross Sectional Area			Cross Sectional Area		
Begin Dist	End Dist	Begin Dist	End Dist	Transect (in)	Inter-val (in)	Area	Transect (in)	Inter-val (in)	Area	Transect (in)	Inter-val (in)	Area

Figure 1. Photographs illustrating different types of boundary determinations. Trail tread boundaries are defined as the most pronounced outer boundary of visually obvious human disturbance created by trail use (not trail maintenance like vegetation clearing). These boundaries are defined as pronounced changes in ground vegetation height (trampled vs. untrampled), cover, composition, or, when vegetation cover is reduced or absent, as pronounced changes in organic litter (intact vs. pulverized). The objective is to define the trail tread that receives the majority (>80%) of traffic, selecting the most visually obvious boundary that can be most consistently identified by you and future trail surveyors.

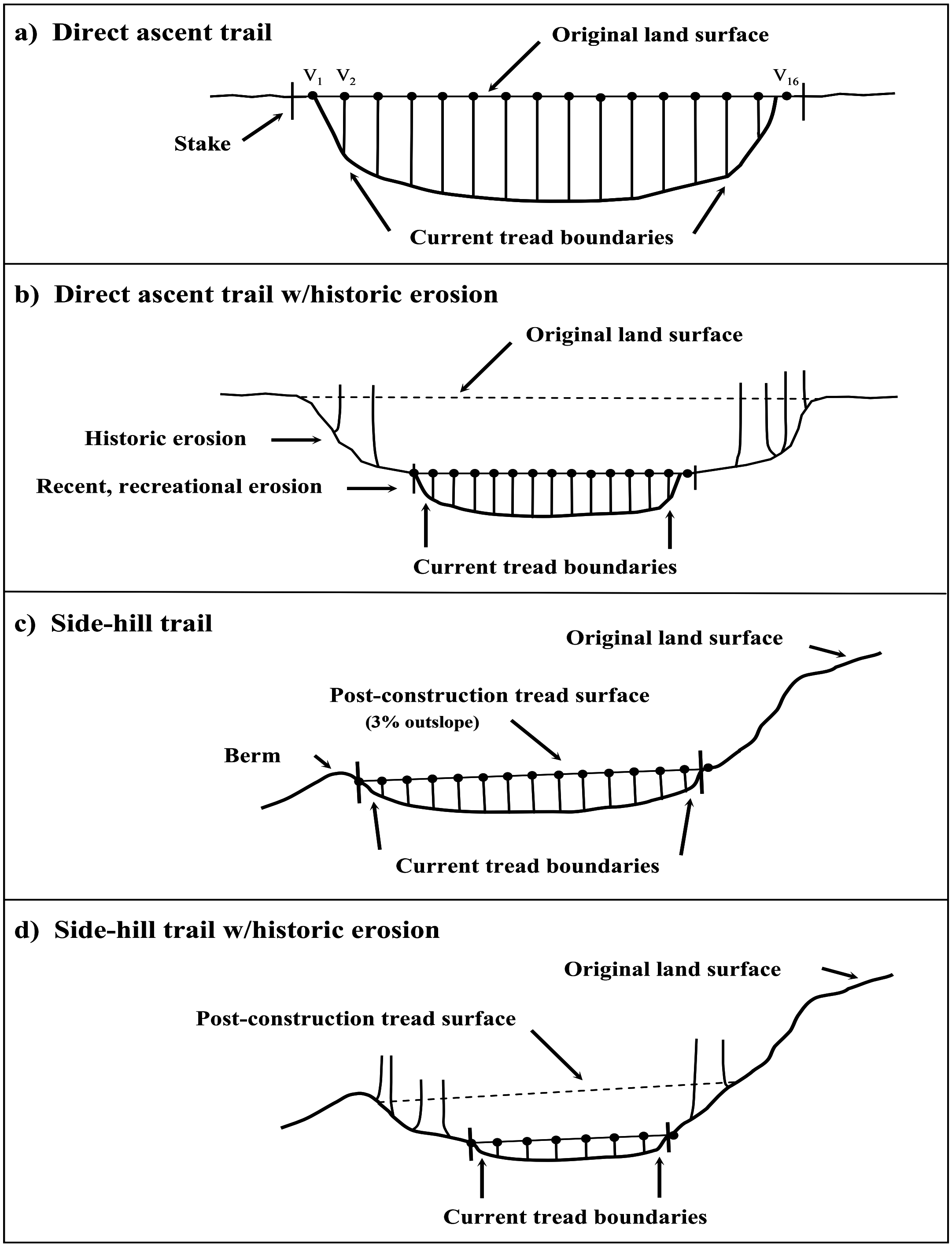


Figure 2. Diagrams illustrating alternative tread incision measurements in terrain where cut and fill work was not performed during tread construction (a-c) and in terrain where sidehill construction involved the excavation of substrate to create a tread surface (d-f).

This manual describes standardized procedures for conducting an assessment of resource conditions on formal (designated) and informal (visitor-creation) recreation trails within Haleakala National Park. For formal trails the principal objective of these procedures is to document and monitor changes in trail conditions following construction. Their design relies on a sampling approach to characterize trail conditions from measurements taken at transects located every 500 feet along randomly selected trail segments. Distances are measured with a measuring wheel. Measurements are conducted at sample points to document the trail's width, depth, substrate, slope, alignment and other characteristics. These procedures take approximately three minutes to apply at each sample point. Data is summarized through statistical analyses to characterize resource conditions for each trail segment and for the entire trail system. During future assessments it is not necessary to relocate the same sample points for repeat measures. Survey work should be conducted during the middle or end of the primary use season. Subsequent surveys should be conducted at approximately the same time of year. For informal trails the procedures track changes in the number and lineal extent of informal trails by GPS surveys of existing trails within defined zones. Condition class assessments of each trail are used to track changes in their general condition.

Materials

(Check before leaving for the field)

- This manual on waterproof paper
- Field forms - some on waterproof paper
- Topographic and driving maps
- Clipboard
- Pencils
- Tape measure (12ft)
- Measuring wheel
- Peep-hole Compass
- 20 ft fiberglass tape measure marked off every 0.3 ft
- Stakes (3)
- Clinometer

Point Sampling Procedures

Trail Segments: During the description of amount and type of use (indicators 5 & 6 below) be sure that the use characteristics are relatively uniform over the entire trail segment. Sampled trails may have substantial changes in the type or amount of use over their length. For example, one portion of a trail may allow horse use or a trail may join the study trail, significantly altering use levels. In these instances where substantial changes in the type and/or amount of use occur, the trail should be split in two or more segments and assigned separate names and forms, upon which the differences in use can be described. This practice will facilitate the subsequent characterization of trail use and statistical analyses.

Also collect and record any other information that is known about the trail's history, such as original construction, past uses, type and amount of maintenance, history of use, etc.

General Trail Information

1) Trail Sgment Code: Record a unique trail segment code (can be added later).

2) Trail Name: Record the trail segment name(s) and describe the segment begin and end points.

3) Surveyors: Record initials for the names of the rail survey crew

4) Date: Record the date (mm/dd/yr) the trail was surveyed.

5) Use Level (UL): Record an estimate of the amount of use the trail receives (high, med., low), relative to other park trails, from the most knowledgeable staff member. Work with them to quantify use levels on an annual basis (e.g., low use: about 100 users/wk for the 12 wk use season, about 30 users/wk for the 20 wk shoulder season, about 10 users/wk for the 20 wk off-season = about 2000 users/yr).

6) Use Type (UT): Record estimates for the types of use the trail receives (including any illegal uses) using percentages that sum to 100%. These should be provided by the most knowledgeable park staff member. Categories might include: Hiking, Horseback, Biking, Other (specify).

Starting/Ending Point: Record a brief description of the starting and ending point of the trail survey. Try to choose identifiable locations like the center of intersections with other trails, roads, or permanent trailhead signs. Record a GPS waypoint and record the WP# for start and end points on the Point Sampling Form. If managers have an accurate and current map of the surveyed trail it is not necessary to GPS it again.

Measuring Wheel Procedures: At the trail segment starting point, select a random from 0 to 500. Record this number on the first row of the form. This will be the first sample point, from which all subsequent sample points will be located in 500 foot intervals. This procedure ensures that all points along the trail segment have an equal opportunity of being selected. Once you get to the first sample point, reset the wheel counter and use it to stop at 500 foot intervals thereafter.

Push the measuring wheel along the middle of the tread so that it does not bounce or skip in rough terrain. Lift the wheel over logs and larger rocks, adding distance manually where necessary to account for horizontal distances. Your objective is to accurately measure the distance of the primary (most heavily used) trail tread. Monitor the wheel counter closely and stop every 500 feet to conduct the sampling point measures. If you go over this distance, you can back the wheel up to the correct distance. If the wheel doesn't allow you to take distance off the counter then stop immediately and conduct your sampling at that point, recording the actual distance from the wheel, not the "missed" distance.

If an indicator cannot be assessed, e.g., is "Not Applicable" code the data as -9, code missing data as -1.

Rejection of a sample point: Given the survey's objective there will be rare occasions when you may need to reject a sampling point due to the presence of: 1) bedrock or cobble stone areas that lack defined trail boundaries, and 2) uncharacteristic settings, like tree fall obstructions, trail intersections, road-crossings, stream-crossings, bridges and other odd uncommon situations. The data collected at sample points should be "representative" of the 250 foot sections of trail on either side of the sample point. Do not relocate a point to avoid longer or common sections of bog bridging, turnpiking, or other trail tread improvements. Use your judgment but be conservative when deciding to relocate a sample point. The point should be relocated by moving forward along the trail an additional 30 feet, this removes the bias of subjectively selecting a point. If the new point is still problematic then add another 30 feet, and so on. Record the actual distance of the substituted sample point and then push the wheel to the next sample point using the original 500 foot intervals.

7) Distance: In the first column record the measuring wheel distance in feet from the beginning of the trail segment to the sample point.

8) Erosion Type (ET): Assess erosion at the sample point as one of the following (see definitions in #14).

0 – Limited erosion < 0.5ft, RE – Recent erosion, HE – Historic erosion

9) Trail Grade (TG): The two field staff should position themselves on the trail 5 ft either side of the transect. A clinometer is used to determine the grade (% slope) by sighting and aligning the horizontal line inside the clinometer with a spot on the opposite person at the same height as the first person's eyes. Note the percent grade (right-side scale in clinometer viewfinder) and record (indicate units used). Note: if conducted by one person then place clinometer on a clipboard with the window facing you. Orient the clipboard to be parallel to the trail grade and record degrees off the visible scale in the window. Be sure to note the units (degrees) and convert the data to percent slope = [tan (degrees)] x 100 after field work.

10) Landform Grade (LG): Assess an approximate measure of the prevailing landform slope in the vicinity of the sample point. Follow the one-person procedure described in #9. Note that if the trail is located in a valley bottom with the terrain on both trail sides sloping up then landform grade is equal to the trail grade.

11) Trail Slope Alignment Angle (TSA): Assess the trail's alignment angle to the prevailing land-form in the vicinity of the sample point. Position yourself about 5 ft downhill along the trail from the transect and sight a compass along the trail to a point about 5ft past the transect; record the compass azimuth (0-360, not corrected for declination) on the left side of the column. Next face directly upslope (i.e., the fall line where water would flow downhill from a point 15-20 ft away to your feet), take and record another compass azimuth - this is the aspect of the local landform. The trail's slope alignment angle ($<90^0$) is computed by subtracting the smaller from the larger azimuth (done after data entry). Note, if water would flow down to the transect from both sides and there is nothing lower than the trail (i.e., water would drain down the tread), then record the same azimuth measure. If water would flow down to a lower area next to the trail then the trail at that point is still assessed as a side-hill trail.

12) Secondary Treads (ST): Count the number of trails, regardless of their length, that closely parallel the main tread at the sample point. *Do not count the main tread.*

13) Tread Width (TW): From the sample point, extend a line transect in both directions perpendicular to the trail tread. Identify the endpoints of this trail tread transect as the most pronounced outer boundary of visually obvious human disturbance created by trail use (not trail maintenance like vegetation clearing). These boundaries are defined as pronounced trampling-related changes in ground vegetation height (trampled vs. untrampled), cover, composition, or, when vegetation cover is reduced or absent, changes in organic litter (intact vs. pulverized) (see photo illustrations in Figure 1). The objective is to define the trail tread that receives the majority (>95%) of traffic, selecting the most visually obvious outer boundary that can be most consistently identified by you and future trail surveyors. Include any secondary

parallel treads within the transect only when they are not differentiated from the main tread by strips of less disturbed (taller) vegetation or organic litter (see the tread boundary description).

Also pay close attention to selecting boundary points that reflect the extent of soil loss representative for this location along the trail. Soil loss measures will be taken from a tape stretched between the endpoints you select so the tape should be unobstructed. Organic litter or small rocks that obstructs the tape can be removed but large rock or root obstructions will necessitate moving the tape forward along the trail in one foot increments until you reach a location where the tape is unobstructed. Temporarily place stakes at the boundary points and then step back to verify their horizontal and vertical placement as projected along the trail in the vicinity of the sample point.

Measure and record the length of the transect (tread width) to the nearest inch (don't record feet and inches).

14) Cross-Sectional Area, Current Tread (C-CSA): The objective of the CSA measure is to estimate soil loss from the tread at the sample point following trail creation. Accurate and precise CSA measures require different procedures based on the type of trail and erosion, some definitions:

Direct-ascent vs. side-hill trails: Trails, regardless of their grade, that more or less directly ascend the slope of the landform are direct-ascent or "fall-line" trails. Direct-ascent trails involve little or no tread construction work at their creation – generally consisting of removal of organic litter and/or soils. Trails that angle up a slope *and* require a noticeable amount of cut-and-fill digging in mineral soil (generally on landform slopes of greater than about 10%) are termed side-hill trails. The movement of soil is required to create a gently out-sloped bench to serve as a tread. Separate procedures are needed for side-hill trails to avoid including construction-related soil movement in measures of soil loss following construction.

Recent vs. historic erosion: Recreation-related soil loss that is relatively recent is of greater importance to protected land managers and monitoring objectives. Severe erosion from historic, often pre-recreational use activities, is both less important and more difficult to reliably measure. Historic erosion is defined as erosion that occurred more than 10-15 years ago and is most readily judged by the presence of trees and shrubs growing from severely eroded side-slopes.

a) <u>Direct-ascent trails, recent erosion</u>: Refer to Figure 2a and follow these procedures. Place two stakes and the transect tape line to characterize what you judge to be the pre-trail or original land surface. Place the left-hand stake at the trail boundary and attach the tape so that the bottom of the tape will fall on what you believe was the “original” ground surface but at the edge of any tread incision, if present (see Figure 2). Stretch the transect line tightly between the two stakes - any bowing in the middle will bias your measurements. Insert the other stake just beyond the first transect line mark on the other side of the trail that is on the original ground surface and will be measured as a 0. The transect line should reflect your estimate of the pre-trail land surface, serving as a datum to measure tread incision caused by soil erosion and/or compaction.

Note: For this and all other options (b-d), if the trail is wide or if the tread surface is relatively homogeneous then the interval between vertical measures can be extended from 0.3 ft to 0.5 or even 1.0 ft. Label the field form clearly whenever this option is used so that CSA calculations can be done correctly.

Trail Width	3% outslope
20	0.6"9
30	0.9"9
40	1.2"9
50	1.5"9
60	1.8"9
70	2.1"9
80	2.4"9
90	2.7"9
100	3.0"9
110	3.3"9
120	3.6"9
130	3.9"9
140	4.2"9
150	4.5"9

b) Direct-ascent trails w/historic erosion: Refer to Figure 2b – if you judge that some of the erosion is historic then follow these procedures. Generally you will find an eroded tread within a larger erosional feature. Place two stakes and stretch the transect line to reflect and allow measurements of the more recent recreation-related erosion (if present). If there is no obvious recent-erosion tread incision then position the stakes the same as for your tread width measurement and assess incision between tread boundaries (option not depicted in Figure 2b). The left-hand stake can serve as transect 1, record a 0 for this. At the right boundary you must also record a transect with a measure of 0.

c) Side-hill trail: Refer to Figure 2c. The objective of this option is to place the transect stakes and line to simulate the post-construction tread surface, thereby focusing monitoring measuresments on post-construction soil loss and/or compaction. When side-hill trails are constructed, soil on the upslope side of the trail is removed and deposited downslope to create a gently out-sloped bench (most agency guidance specify a 5% outslope) for the tread surface. Outsloped treads drain water across their surface, preventing the buildup of larger quantities of water that become erosive. However, constructed treads often become incised over time due to soil erosion and/or compaction. The extent of this incision are what these procedures are designed to estimate.

Carefully study the area in the vicinity of the sample point to judge what you believe to be the post-construction tread surface. Pay close attention to the tree roots, rocks or more stable portions of the tread to help you judge the post-construction tread surface. Look in adjacent undisturbed areas to see if roots are exposed naturally or the approximate depth of their burial.

Configure the stakes and transect line to approximate what you judge to be the post-construction tread surface. Note that sometimes a berm of soil, organic material and vegetation will form on the downslope side of the trail that is raised slightly above the post-construction tread surface. If present, place the stake and line below the height of the berm as shown in Figure 2c so that it does not influence your measurements. If erosion is severe and/or if the line placement is subjective, use a line level with to configure the line as a 3% outslope (see table of values at right) to standardize the line placement and reduce measurement error. An outslope of 3% is used because actual tread construction is often somewhat less than 5%, and 3% provides a more conservative estimate of soil loss. Measure the left-hand stake as transect 1 with a 0 measure and also record an additional transect beyond the right-hand stake with a measure of 0.

<u>Side-hill trail with historic erosion</u>: Refer to Figure 2d - if you judge that the erosion is historic then follow these procedures. Generally you will find an eroded tread within a larger erosional feature. Place two stakes and stretch the transect line to reflect and allow measurements of the more recent recreation-related erosion (if present). Since the current tread is well below the original tread there is no need to use the 3% outslope procedure described above. The left-hand stake can serve as vertical transect 1, record a 0 for this. At the right boundary you must also record a vertical transect with a measure of 0.

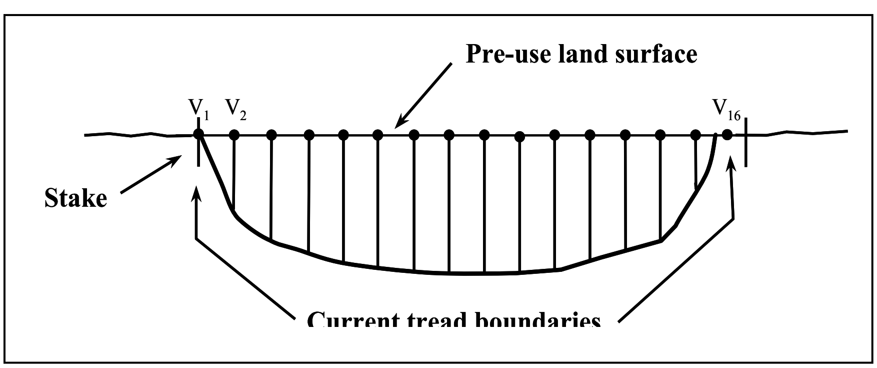


Illustration of the variable interval CSA method for assessing soil loss at each transect.

Measurement

Procedure: On the CSA data form, label a new row with the measuring wheel distance for the transect (e.g., D=600 ft). Starting on the left side with a "zero" measurement, measure from each vertical transect line marking, a perpendicular transect down to the ground surface (nearest 1/4 in, e.g., .25, .5, .75). If water is present measure to the substrate beneath. Record the values on the data sheet next to their labeled transect numbers (e.g., V_1, V_2, $V_3 \ldots V_n$). Continue measuring each transect height until you reach the far side of the trail and obtain a measure of 0. ***Note:*** The transect line is not likely to be "level" so be cautious in measuring vertical transects that are *perpendicular* to the horizontal transect line.

In the office, use a spreadsheet to compute and sum cross-sectional area values with the following formula for each consecutive pair of vertical transect measures and using the equation: Area = $(V_i + V_{i+1}) \times I_i \times .5$ for each row and summed to compute CSA (I = interval distance between vertical measurements).

15) **<u>Maximum Incision, Current Tread (MIC):</u>** Measure the maximum incision (nearest 1/4 inch: record .25, .5, .75) from the tape to the deepest portion of the trail tread. Your objective is to record a measure that reflects the maximum amount of soil loss along the transect within the tread boundaries.

16) **<u>Cross-Sectional Area, Original Tread (O-CSA):</u>** If the transect is located at a place with historic erosion (Figures 2b or 2d) then also apply this indicator to assess the extent of historic erosion. Reconfigure the stakes and tape measure to conform to the dashed "original land surface" line shown in Figure 2b or the "post-construction tread surface" line shown in Figure 2d. Repeat the CSA measures, making sure to label the data as P-CSA on the data form. This measure can be made more efficient where needed by lengthening the interval between vertical measures (e.g., extended from .3 ft to .5 or 1.0 ft). Label the field form clearly whenever

this option is used so that CSA calculations can be done correctly. If the erosion is over your head then attempt some crude estimates by measuring the dimensions of a rectangle and two right triangles for this location.

17-26) **Tread Condition Characteristics:** Along the trail tread width transect, estimate to the nearest 10% (5% where necessary) the aggregate lineal length occupied by any of the mutually exclusive tread surface categories listed below. **Be sure that your estimates sum to 100%**.

S-Soil:	All soil types including sand and organic soils, excluding organic litter unless it is highly pulverized and occurs in a thin layer or smaller patches over bare soil.
L-Litter:	Surface organic matter including intact or partially pulverized leaves, needles, or twigs that mostly or entirely cover the tread substrate.
V-Vegetation:	Live vegetative cover including herbs, grasses, mosses rooted within the tread boundaries. Ignore vegetation hanging in from the sides.
R-Rock:	Naturally-occurring rock (bedrock, boulders, rocks, cobble, or natural gravel). If rock or native gravel is embedded in the tread soil estimate the percentage of each and record separately.
M-Mud:	Seasonal or permanently wet and muddy soils that show imbedded foot or hoof prints from previous or current use (omit temporary mud created by a very recent rain). The objective is to include only transect segments that are frequently muddy enough to divert trail users around problem.
G-Gravel:	Human-placed (imported) gravel.
RT-Roots:	Exposed tree or shrub roots.
W-Water:	Portions of mud-holes with water or water from intercepted seeps or springs.
WO-Wood:	Human-placed wood (water bars, bog bridging, cribbing).
O-Other:	Specify.

Collect all equipment and move on to the next sample point. **Be sure to assess and record information on the Problem Assessment indicators as you proceed to the next sample point.** These indicators are assessed continuously as pre-defined trail tread problems and when found, surveyors record begin and end distances (from the start of the survey) on the Problem Assessment Form. **Note: after data entry and before analysis the data for these indicators need to be corrected to add in the 1st randomly selected interval distance so that**

location data are accurate. In particular, examine any indicators that may begin before and end after the first sample point.

Problem Assessment Procedures

27) **Informal Trails (IT):** Record the trail distance from the measuring wheel for each informal (visitor-created) trail that intersects the survey trail segment, and/or occurs within the defined survey zones. Take a GPS waypoint and record the WP# on the form, along with a condition class rating (see below) selecting the most representative category for the entire trail. Turn on the tracking feature and walk the length of the informal trail. If another informal trail branches from the first informal trail then complete the first trail, suspend the tracking function, walk back to the intersection, take another GPS waypoint, record the WP# and condition class for the 2nd trail, turn on the tracking feature and walk that one as well.

Informal trails are trails that visitors have created to access features such as streams, scenic attraction sites1, cliffs, vistas, cultural sites, or to cut switchbacks, avoid mud-holes, rutted treads, steep obstacles, or downed trees, or that simply parallel the main trail. Do not count formal trails, roads of any type, extremely faint trails with untrampled vegetation in their treads, trails <10 ft long, or trails that have been effectively blocked off by managers, and disregard the other end of the trail if it reconnects to the survey trail. Include any distinct animal or game trails as these are generally indistinguishable from human trails and their true origin is likely unknown.

Class 0: Trail barely distinguishable; no or minimal disturbance of vegetation and/or organic litter.

Class 1: Trail distinguishable; slight loss of vegetation cover and/or minimal disturbance of organic litter.

Class 2: Trail obvious; vegetation cover lost and/or organic litter pulverized in primary use areas.

Class 3: Vegetation cover lost and/or organic litter pulverized within the center of the tread, some bare soil exposed.

Class 4: Nearly complete or total loss of vegetation cover and organic litter within the tread, bare soil widespread.

Class 5: Soil erosion obvious, as indicated by exposed roots and rocks and/or gullying

28) **Muddy Soil (MS):** Sections of tread (≥10 ft) with seasonal or permanently wet and muddy soils that show imbedded foot or hoof prints (≥½ inch). Omit temporary muddiness created by a recent rain. This should generally include any longer mud-holes or treads with running water. The objective is to include only tread segments that are frequently wet or muddy enough to divert trail users around the problem, often leading to an expansion of trail width.

29) **Soil Erosion (SE):** Sections of tread (≥10 ft) with soil erosion exceeding 6 inches in depth within current tread boundaries. Record SE1 for soil loss 5-10 in., SE2 for 10.1-15 in. and SE3 for 15.1-20 in.

Figure 1. Photographs illustrating different types of boundary determinations. Trail tread boundaries are defined as the most pronounced outer boundary of visually obvious human disturbance created by trail use (not trail maintenance like vegetation clearing). These boundaries are defined as pronounced changes in ground vegetation height (trampled vs. untrampled), cover, composition, or, when vegetation cover is reduced or absent, as pronounced changes in organic litter (intact vs. pulverized). The objective is to define the trail tread that receives the majority (>80%) of traffic, selecting the most visually obvious boundary that can be most consistently identified by you and future trail surveyors.

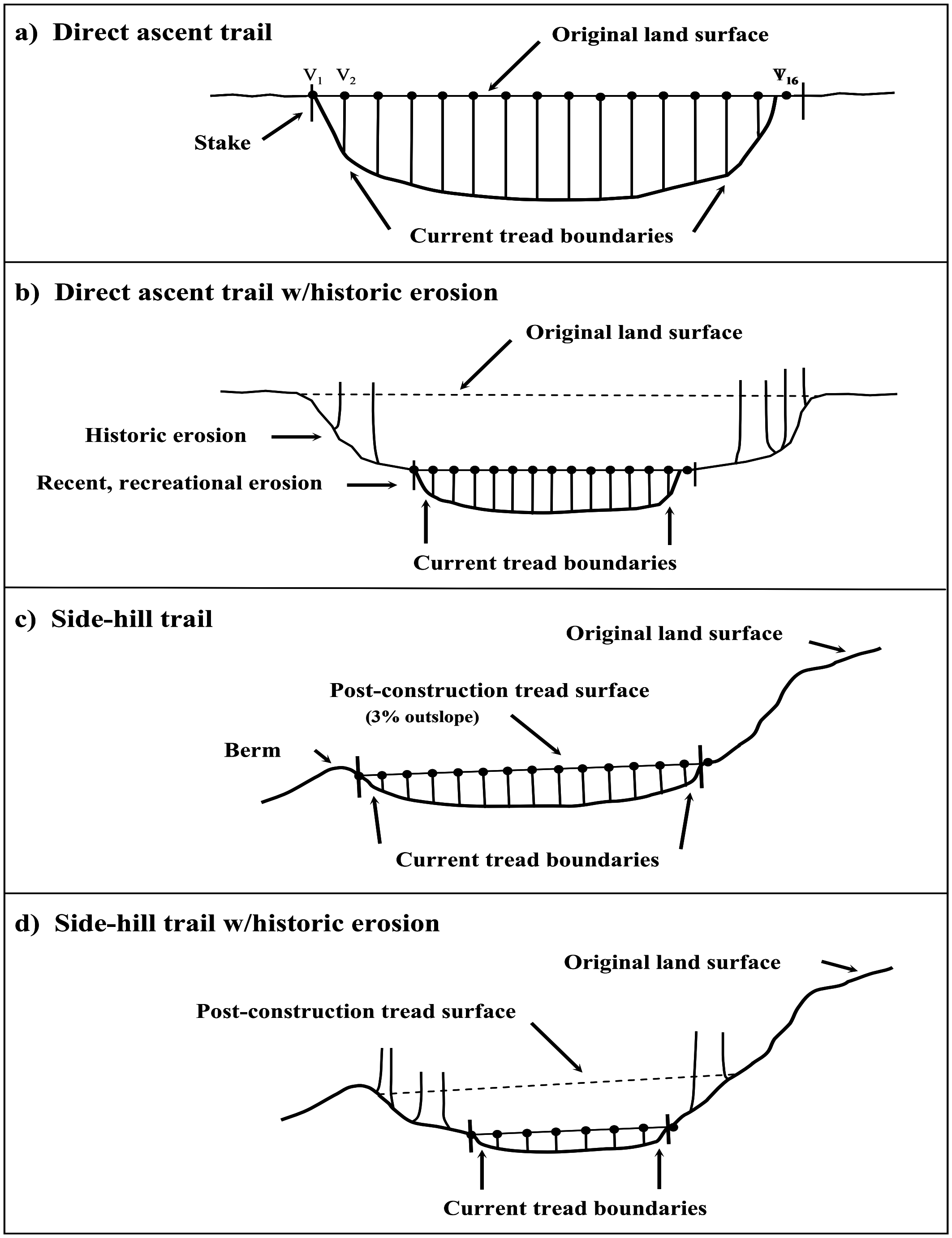


Figure 2. Cross sectional area (CSA) diagrams illustrating alternative measurement procedures for direct ascent trail alignments (a & b) vs. side-hill trail alignments (c & d) and for relatively recent erosion (a & c) vs. historic erosion (b & d).

Point Sampling Form

Trail Segment Code ________ **Trail Name** ____ **Surveyors** ________________

Date ________ **Use Level** ________ **Use Type(s):** Hiker ______%, Horse ______%, Bike ______%, Other ______%

Starting Point: **WP#:**______________________________

Ending Point: **WP#:**______________________________

Dist	ET	TG	LG	TSA	ST	TW	Tread Substrate Characteristics	MIC	C-CSA	O-CSA
				/						
				/						
				/						
				/						
				/						
				/						
				/						
				/						
				/						
				/						
				/						
				/						
				/						
				/						
							0 10 20 30 40 50 60 70 80 90 100			

Dist = Wheel Distance
TT = Trail Type (DA, SH)
ET = Erosion Type (RE, HE)form)
TG = Trail Grade
LG = Landform Grade

TSA = Alignment (Trail° / Landform°)
ST = Secondary Treads
TW = Tread Width
MIC = Max. Incision
CSA (calculated from data)

S = Soil
L = Litter
V = Vegetation
R = Rock
M = Mud

G = Gravel
RT = Roots
W = Water
WO = Wood, human-placed
O = Other (Specify)

Problem Assessment Form / Cross Sectional Area Form

Trail Segment Code ________ **Trail Name** ______________________________

Informal Trails	Muddy Soil		Soil Erosion		CSA		CSA		CSA	
Distances	Begin Dist	End Dist	Begin Dist	End Dist	Transect (in)	Area	Transect (in)	Area	Transect (in)	Area
					D=					
					V_1=					

Hoosier National Forest Field Manual
(Developed by Dr. Jeff Marion)

Introduction

This manual describes standardized procedures for conducting an assessment of resource conditions on recreation trails. The principal objective of these procedures is to document and monitor changes in trail conditions following construction or creation. Their design relies on a sampling approach to characterize trail conditions from measurements taken at transects located every 300 ft (91 m) along selected trail segments. Distances are measured with a measuring wheel. Measurements are conducted at sample points to document the trail's width, depth, substrate, slope, alignment and other characteristics. These procedures take between 3 to 6 minutes to apply at each sample point. Data is summarized through statistical analyses to characterize resource conditions for each trail segment. During future assessments it is not necessary to relocate the same sample points for repeat measures. Survey work should be conducted during the middle or end of the primary use season during the growing season. Subsequent surveys should be conducted at approximately the same time of year.

Materials

This manual on waterproof paper, Field forms (both types) - some on waterproof paper, Pencils, Clipboard w/compartment for forms, Measuring wheel, Topographic and driving maps, Clinometer, 12 ft Tape measure (& 25ft for wide trails), Metal stakes (3), Compass, 25 ft 1/16 in. braided nylon string with 18 beads attached, Trowel

Point Sampling Procedures

Trail Segments: During the description of amount and type of use (indicators 5 & 6 below) be sure that the use characteristics are relatively uniform over the entire trail segment. Some of the study trails have multiple uses. For example, a sign in the middle of a study segment restricting horse use beyond it can substantially affect visitation and impact. Even when use types are not regulated the study trail may intersect with another route that diverts one of the user groups. In such instances where substantial changes in the type and/or amount of use occur, the trail should be split in two segments and assigned separate names and forms, upon which the differences in use can be described. This practice will facilitate subsequent statistical summaries and analyses. Also collect and record any other information that is known about the trail's history, such as original construction, past uses, type and amount of maintenance, history of use, etc.

1) Trail Segment Code: Record a unique trail segment code (can be added later).

2) Trail Name: Record the trail segment name(s) and describe the segment begin and end points.

3) Surveyors: Record initials for the names of the trail survey crew.

4) Date: Record the date (mm/dd/yr) the trail was surveyed.

5) Use Level (UL): Record an estimate of the amount of use the trail receives, relative to all trails in the forest, from the most knowledgeable forest staff member: High, Medium, Low. Work with them to quantify these use levels on an annual basis (e.g., low use, < 100 users/wk for the 12 wk use season, < 30 users/wk for the 20 wk shoulder season, < 10 users/wk for the 20 wk off-season = < 2000 users/yr).

6) Use Type (UT): Record estimates for the types of use the trail receives (including any illegal uses) using percentages that sum to 100%. These should be provided by the most knowledgeable forest staff member. Categories include: Hiking, Horseback, Vehicle, ATV, Bike, Other (specify).

Starting/Ending Point: Record a brief description of the starting and ending points of the survey. Try to choose identifiable locations like intersections with other trails, roads, or permanent trailhead signs.

Measuring Wheel Procedures: At the trail segment starting point, select a random number from 0 to 300. Record this number on the first row of the form. This will be the first sample point, from which all subsequent sample points will be located in 300 ft intervals. This procedure ensures that all points along the trail segment have an equal opportunity of being selected. Once you get to the first sample point, reset the wheel counter and use it to stop at 300 ft intervals thereafter.

Push the measuring wheel along the middle of the tread so that it does not bounce or skip in rough terrain. Lift the wheel over logs and larger rocks, adding distance manually where necessary to account for horizontal distances. Your objective is to accurately measure the distance of the primary (most heavily used) trail tread. Monitor the wheel counter and stop every 300 ft to conduct the sampling point measures. If you go over this distance, you can back the wheel up to the correct distance. If the wheel doesn't allow you to take distance off the counter then stop immediately and conduct your sampling at that point, recording the actual distance from the wheel, not the "missed" distance.

If an indicator cannot be assessed, e.g., is "Not Applicable" code the data as -9, code missing data as -1.

Rejection of a sample point: Given the survey's objective there will be rare occasions when you may need to reject a sampling point due to the presence of boulders, tree falls, trail intersections, road-crossings, stream-crossings, bridges or other odd "uncharacteristic" situations. The data collected at sample points should be "representative" of the 150 ft sections of trail on either side of the sample point. Do not relocate a point to avoid longer or common sections of bog bridging, turnpiking, or other trail tread improvements. Use your judgment but be conservative when deciding to relocate a sample point.

The point should be relocated by moving forward along the trail an additional 30 ft, this removes the bias of subjectively selecting a point. If the new point is still problematic then add another 30 ft, and so on.

7) Distance: In the first column record the measuring wheel distance in feet from the beginning of the trail segment to the sample point.

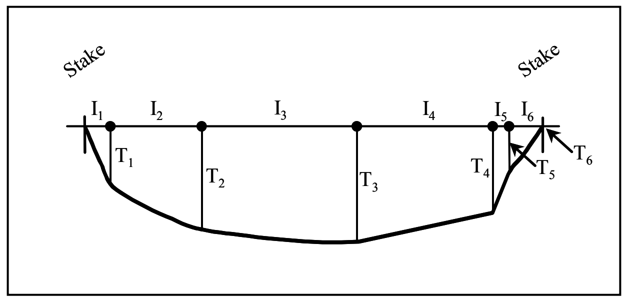
8) Secondary Treads (ST): Count the number of trails that parallel the main tread at the sample point. Count all treads regardless of their length. *Do not count the main tread*.

9) Tread Width (TW): From the sample point, extend a line transect in both directions perpendicular to the trail tread. Identify the endpoints of this trail tread transect as the most pronounced outer boundary of visually obvious human disturbance created by trail use (not trail maintenance like vegetation clearing). These boundaries are defined as pronounced changes in ground vegetation height (trampled vs. untrampled), cover, composition, or, when vegetation cover is reduced or absent, as pronounced changes in organic litter (intact vs. pulverized) (see photo illustrations in Figure 1). The objective is to define the trail tread that receives the majority (>95%) of traffic, selecting the most visually obvious outer boundary that can be most consistently identified by you and future trail surveyors. Include any secondary treads (see #9) within the transect unless there are undisturbed areas between treads (as defined by the tread boundary definition). In this latter case, establish the transect and conduct measurements for the primary tread. Temporarily place stakes at the boundary points. Note: incision and cross-sectional area measures will be taken from this line so it should be unobstructed. If raised up by soil or litter then push down the obstructing materials. If pushed up substantially by rocks or roots then move the line forward along the trail in one-foot increments until you reach a location where the line is unobstructed. Measure and record the length of the transect (the tread width) to the nearest inch (don't record feet and inches).

10) Maximum Incision, Current Tread (MIC): Stretch the nylon string tightly between the two stakes that define the tread boundaries - any bowing in the middle will bias your measurements.

Position the string so that it can be used as a datum to measure tread incision caused by soil erosion and/or compaction. Note that this string will likely not be "level" (i.e., if a bubble level were placed along it). Measure the maximum incision (nearest 1/4 in: record .25, .5, .75) from the string to the deepest portion of the trail tread. Measure to the surface of the tread's substrate, not the tops of rocks or the surface of mud puddles. Your objective is to record a measure that reflects the maximum amount of soil loss along the transect within the tread boundaries. See Figure 2, noting differences in MIC measures for side-hill vs. non-side-hill trails.

11) Cross-Sectional Area (CSA): On the Cross Sectional Area form, record the distance from the measuring wheel. Record a 0 in the Area column and skip this procedure if the maximum incision is #1 in. Otherwise complete the following:



Starting at the left tread boundary, position beads (or twist ties) along the nylon string so that they are above tread surface locations that, if connected with straight lines, would accurately characterize the tread cross-section (see figure).

Measure and record the distance to each bead from the left stake. It's most efficient (and accurate) to record the cumulative measures from the left stake. Note: if measuring is done as you position the beads you may be able to place them at whole-inch intervals, otherwise record to the nearest 1/4 in.

Transect (in)	Interval (in)	Area
Dist: 2500		
T1: 4.25	2.5 I1: 2.5	5.31
T2: 7.5	8.75 I2:	36.72
T3: 9.75	18.5 I3:	84.09
T4: 6.0	27.0 I4: 8.5	66.94
T5: 2.75	28.25 I4:	5.47
T6: 0	31.0 I5:	3.78
		202.3

Measure (nearest 1/4 in: record .25, .5, .75) each vertical transect oriented perpendicular (90^o) from the line down to the tread surface beginning with the first bead and ending with the other stake ($T_n = 0$).

Compute and sum cross-sectional area with the following formula: Area = (Transect 1 + Transect 2) x Interval x .5 for each row and summed for the total area of soil loss. Note: the author has a computer program that calculates CSA with transect and cumulative interval measures as input. Contact author to obtain a copy.

12-22) **Tread Condition Characteristics:** Along the trail tread width transect, estimate to the nearest 10% (5% where necessary) the aggregate lineal length occupied by any of the mutually exclusive tread surface categories listed below. **Be sure that your estimates sum to 100%**. Record these on the form by labeling sections of the appropriate row with the relevant code separated by marked vertical lines indicating the appropriate percentage cover for each code.

S-Soil	All soil types including sand and organic soils, excluding organic litter unless highly pulverized and in a thin layer or smaller patches over bare soil.
L-Litter	Surface organic matter including intact or partially pulverized leaves, needles, or twigs that mostly or entirely cover the tread substrate.
V-Vegetation	Live vegetative cover including herbs, grasses, mosses rooted within the tread boundaries. Ignore vegetation hanging in from the sides.
R-Rock	Naturally-occurring rock (bedrock, boulders, rocks, cobble, or natural gravel). If rock or native gravel is embedded in the tread soil estimate the percentage of each and record separately.
M-Mud	Seasonal or permanently wet and muddy soils that show imbedded foot or hoof prints from previous or current use (omit temporary mud created by a very recent rain). The objective is to include only transect segments that are frequently muddy enough to divert trail users around problem.
G-Gravel	Human-placed (imported) gravel.
MG-Muddy Gravel	Muddy human-placed (imported) gravel.
RT-Roots	Exposed tree or shrub roots.
W-Water	Portions of mud-holes with water or water from intercepted seeps or springs.
WO-Wood	Human-placed wood (water bars, bog bridging, cribbing).
O-Other	Specify.

23) **Gravel Depth (GD):** Use a trowel or other implement to dig into the tread so that human-placed gravel depth can be measured (nearest 1/4 in).

24) **Gravel Size Class (GS):** Record the size class of human-placed gravel present: 1= <1in, 2= 1-2in, 3= >2in, 4=class 3 and either class 1 and/or class 2.

25) **Trail Grade (TG):** The two field staff should position themselves at the sample point and 10 ft upslope along the trail. A clinometer is used to determine the grade (% slope) by sighting and aligning the horizontal line inside the clinometer with a spot on the opposite person at the same height as the first person's eyes. Note the percent grade (right-side scale in clinometer viewfinder) and record.

26) **Trail Alignment (TA):** Assess the trail's alignment angle to the prevailing land-form in the vicinity of the sample point. Sight a compass along the trail from a point about 5ft before the transect to about 5ft past the transect, record the compass azimuth (0-360, not corrected for declination) on the left side of the column (it doesn't matter which direction along the trail you sight). Next face directly downslope, take and record another compass azimuth - this is the aspect of the local landform. The trail's alignment angle ($<90^0$) can be computed by these two azimuths.

27) **Landform Slope (LS):** Position two people about 20 ft apart directly up- and down-slope from the sample point. Use a clinometer to obtain the percent slope of the original (pre-trail) landform. On side-hill trails move as far apart as needed to be above the cut-slope and below any fill material.

28) **Tread Drainage Feature (TD):** Pace, up to 150 ft, to the closest feature in an up-hill direction that is reasonably effective in removing water from the trail tread (e.g., at least 70% of water during a rain event would be diverted off-trail). This may be a human-constructed water bar or drainage dip, a natural feature (e.g., tree root, rock, or dip) or tread outsloping. If the latter, pace to a point where you believe water entering the trail from upslope would travel

down and across the trail and miss going past the sample point. Record the paced distance to the nearest foot. Record a 150 if no features are present within 150 ft.

28) **<u>Trail Position (TP):</u>** Use the descriptions below to determine the trail position of the sampling point. Record the corresponding letter code in the TP column.

R - Ridge: Ridge-top or high plateau position.

S - Shoulder: Shoulder just below ridge tops.

M - Midslope/Sideslope: Mid-slope positions.

F - Foot slope/Toe slope: Foot slope just above valley bottom positions.

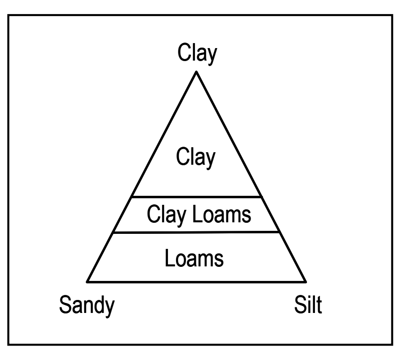
V - Valley Bottom: Flatter valley bottom terrain.

29) **<u>Soil Texture (TX):</u>** Follow the field method described by Foth (1990) to determine the soil texture of the soils in the vicinity of the sample point. Soil texture should not vary substantially along most trails. This assessment should be done at the start of the trail (have some water to use and rinse your hands with). Check the texture without wetting at the sample points and repeat the full method if it appears to have changed.

a) Moisten a sample of soil the size of a golf ball and work it until it's uniformly moist; squeeze it out between the thumb and forefinger to try to form a ribbon.

b) First Decision: If the moist soil is:

* Extremely sticky and stiff, it is a clay.



* Sticky and stiff to squeeze, it is a clay loam.

* Soft, easy to squeeze, and only slightly sticky, it is a loam.

c) Second decision: Add an adjective to refine the description.

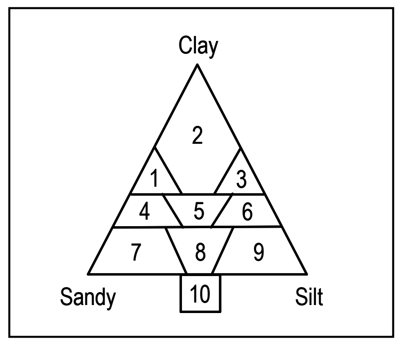
If the soil feels:

* Very smooth, it is silt or silty (# 3, 6, or 9).

* Somewhat gritty, use no adjective (#2, 5, or 8).

* Very, very gritty, it is sandy (# 1, 4, or 7).

d) Combine your (b) and (c) determinations to identify and record the proper classification on the form:



1 - sandy clay	6 - silty clay loam
2 - clay	7 - sandy loam
3 - silty clay	8 - loam
4 - sandy clay loam	9 - silt loam
5 - clay loam	10 - organic soil

30) **Canopy Height (CH):** As per guidance in Universal Soil Loss Equation (USLE) report, record canopy height value.

31) **Canopy Cover (CC):** As per guidance in USLE report, record canopy percent cover value.

32) **Steps (S):** As per guidance in USLE report, record value for steps.

33) **Onsite Storage (OS):** As per guidance in USLE report, record value for onsite storage.

Collect all equipment and move onto the next sample point. **Be sure to record information on indicators 34 & 35 as you proceed to the next sample point.** These indicators are assessed continuously as pre-defined trail tread problems and when found, surveyors record begin and end distances (from the start of the survey) on the Problem Assessment Form. **Note: after data entry and before analysis the data for these indicators need to be corrected to add in the 1st randomly selected interval distance so that location data is accurate. In particular, examine any indicators that may begin before and end after the first sample point.**

Problem Assessment Procedures

34) **Soil Erosion (SE):** Sections of tread (≥10 ft) with soil erosion exceeding 5 in. depth within current tread boundaries. Record beginning and ending distances on the Problem Assessment form.

35) **Muddy Soil (MS):** Sections of tread (≥10 ft) with seasonal or permanently wet and muddy soils that show imbedded foot or hoof prints (≥1in). Omit temporary muddiness created from a recent rain. This should generally include any longer mud-holes or treads with running water. The objective is to include only tread segments that are frequently wet or muddy enough to divert trail users around the problem, often leading to an expansion of trail width.

Point Sampling Form

Trail Segment Code _________ **Trail Name** ____ **Surveyors** _________________

Date _________ **Use Level** ________ **Use Type(s):** Horse ____ %, Hiker ____ %, Vehicle ____ %, ATV ____ %, Bike ____ %

Starting/Ending Point:

Dist	ST	TW	MIC	Tread Substrate Characteristics	GD	GS	TG	TA	LS	TD	TP	TX	CH	CC	S	OS
								/								
								/								
								/								
								/								
								/								
								/								
								/								
								/								
								/								
								/								
								/								
				0 10 20 30 40 50 60 70 80 90												

Dist = Wheel Distance
ST=Secondary Treads
TW=Tread Width
MIC=Max. Incision, Current Tread

S=Soil
L=Litter
V=Vegetation
R=Rock
M=Mud
G=Gravel

MG=Muddy Gravel
RT=Roots
W=Water
WO=Wood, human placed
O=Other (Specify)

GD=Gravel Depth, GS=Gravel Size Class (1-4)
TG=Trail Grade
TA=Alignment (Trail° / Landform°)
LS=Landform Slope, TD=Tread Drainage feature
TP=Trail Posit. (R, S, M, F, V), TX=Texture (1-10)
CH=Canopy Height, CC=Canopy Cover, S=Steps, OS=Onsite Storage

Problem Assessment Form

Cross Sectional Area Form

Trail Segment Code __________ **Trail Name** ____

Soil Erosion		Muddy Soil	
Begin Dist	End Dist	Begin Dist	End Dist

Cross Sectional Area			Cross Sectional Area			Cross Sectional Area		
Transect (in)	Inter-val (in)	Area	Transect (in)	Inter-val (in)	Area	Transect (in)	Inter-val (in)	Area
Dist.=								
T_1=	CI_1=							

Figure 1. **Photographs illustrating different types of boundary determinations. Trail tread boundaries are defined as the most pronounced outer boundary of visually obvious human disturbance created by trail use (not trail maintenance like vegetation clearing). These boundaries are defined as pronounced changes in ground vegetation height (trampled vs. untrampled), cover, composition, or, when vegetation cover is reduced or absent, as pronounced changes in organic litter (intact vs. pulverized). The objective is to define the trail tread that receives the majority (>80%) of traffic, selecting the most visually obvious boundary that can be most consistently identified by you and future trail surveyors.**

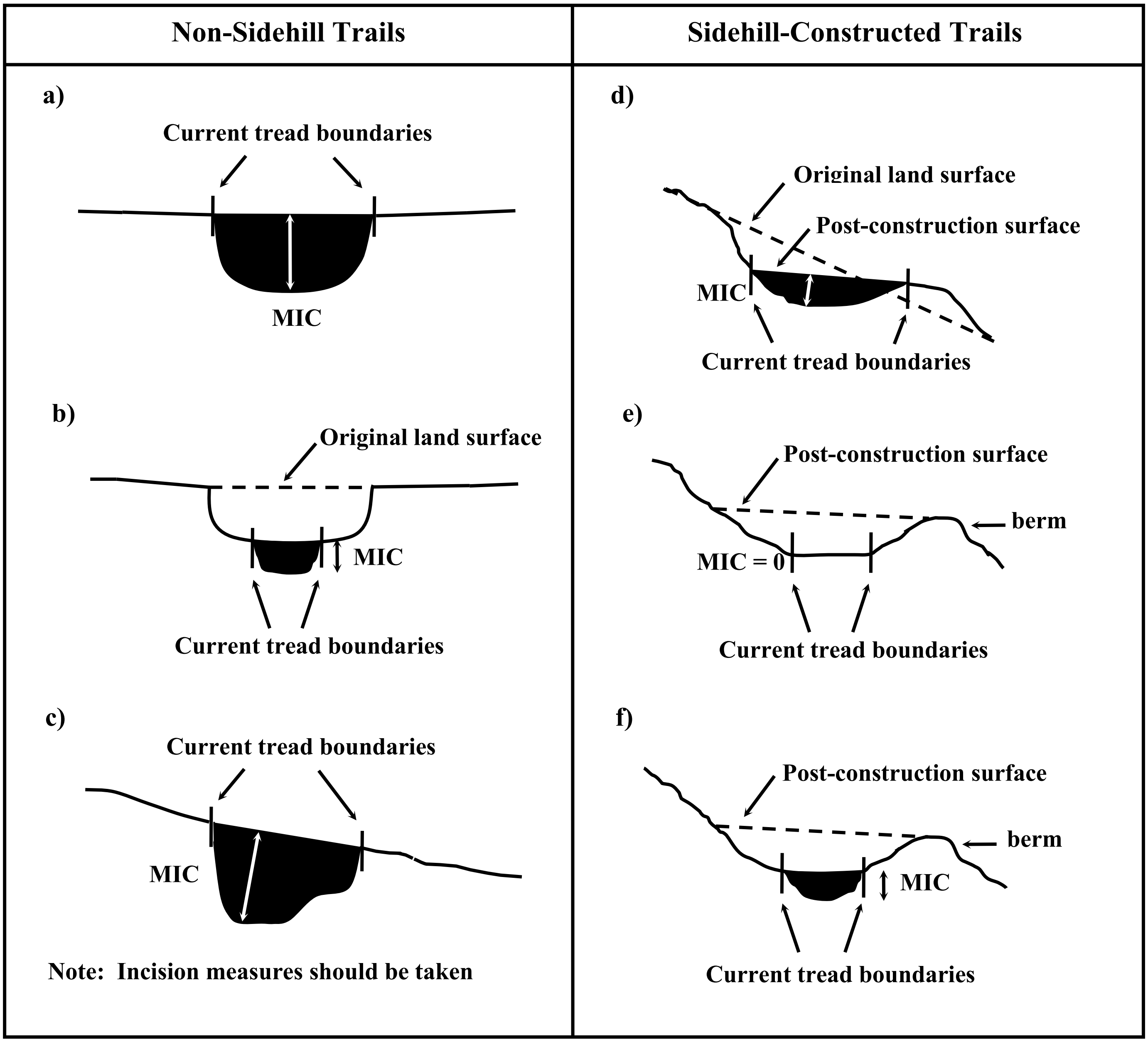


Figure 2. **Diagrams illustrating alternative tread incision measurements in terrain where cut and fill work was not performed during tread construction (a-c) and in terrain where sidehill construction involved the excavation of substrate to create a tread surface (d-f).**

Appendix B – Rocky Mountain National Park Field Protocol

GPS Sampling Protocol

1. Setup
    a. Prepare survey station and wear Virginia Tech t-shirt.
    b. Use fresh GPS batteries in all units each day. Power them all on and setup first track recording.
    c. Setting up track recording:
        i. Press page button to cycle to the Main Menu screen, then use arrow buttons to select Tracks icon, then press enter.
        ii. If recording is not set to ON, then select ON and press enter.
        iii. Select SETUP button and ensure that "wrap when full" and "auto" are enabled. If not, enable them using arrow and enter buttons.
        iv. Press Quit button
2. Sampling
    a. Each hour until GPS units are gone:
        i. Select a random minute between 0 and 60 using the random number table included below.
        ii. Approach the first visitor group to arrive after the sampling minute, and randomly select an adult in the group (member with the closest birthday).
        iii. Check to see that they're finishing at a staffed trailhead.
        iv. Record the contact on the GPS log sheet, record contact information on contact sheet.
        v. Fill out a Matching Card with GPS time, date, GPS ID and location. Place the completed card in the GPS tag; do not cover the return instructions already in the tag.
        vi. Instruct the group that GPS is configured and already running, and instruct the participant to clip the unit to the haul loop/top of a backpack, shirtfront pocket, or other suitably exposed point. Use the included clip attachment or carabiner as necessary.
    b. Returning units:
        i. Thank the group for participating & collect the unit and beltclip
        ii. Press Page button to display Tracks page, highlight save, press enter button, setup GPS for next sampled group (refer to setup, above)
        iii. Ask the participant to complete a GPS Route Exit Survey
        iv. Complete the GPS Exit Survey log entry, recording GPS time from the Matching Card and GPS ID from the return instructions, both found in the GPS tag.
3. End of day
    a. Download/backup all GPS units via MapSource software loaded on laptop at the dorm
        i. Open MapSource software, and select File → New.
        ii. Power on GPS, then connect GPS to computer using USB cable.
        iii. Transfer menu → Receive From Device.
        iv. Select the relevant GPS unit from the list, then check the box next to the tracks you want to backup.
        v. Click receive to transfer the file(s).
        vi. File → Save As to save the tracks to the backup folder(s).
        vii. Delete the tracks from the GPS to ensure adequate memory for subsequent use.
    b. Backup the laptop files to memory sticks
    c. Check for any damaged units, repair, change to fresh batteries

d. Destroy collected contact information for all participants that returned units. Retain contact information for participants that did not return the units.
e. Email backed up data files to Steve (lawsons@vt.edu) weekly, or whenever internet access is available.

Random Number Table

25823	46403	05135	54592	43785	92530	23462	10504	52364
43642	33058	81545	94853	45685	70631	27078	25137	12446
88746	55514	55156	68441	86036	24281	66665	66370	02222
31965	86037	29803	72138	38483	11383	63683	29779	53770
80254	17729	74085	20040	86257	01654	05181	63843	29131
67306	50003	26560	08150	11427	88988	34274	66282	54462
55013	12744	12589	11427	34878	24257	10480	72599	45012
07107	12808	84738	96577	89608	05720	88577	65760	78492
65599	69862	47100	61786	71733	12952	50840	91290	66637
11817	46889	52019	38312	68703	58236	75025	12418	92414
70301	94687	92208	25948	40441	44029	99006	08902	05557
04069	55133	13588	66477	75717	05228	84491	63646	32889
62814	91078	57601	43887	26066	76050	18239	02750	28714
05710	04555	41258	06573	65639	91278	61862	32366	82455
96319	99000	69998	72966	18246	96542	80690	53526	16902
08766	87385	88562	43233	10669	06377	87946	80254	08263
09931	73526	87727	93207	80438	01885	13708	01356	93408
25827	43412	25195	41318	84244	32547	95170	65055	91349
22518	28140	87177	42827	90771	16397	25863	60293	74551
29666	65503	28861	92317	46085	85326	70108	31472	79692
93362	87910	96901	14263	50835	27019	04388	95424	07823
97205	74354	48104	67961	51143	29493	43284	52229	58739
30038	50382	28855	07368	37704	83846	46906	99708	01362
78114	19944	87001	05904	66826	21352	38346	06548	14143
24842	45990	94679	88323	84815	18787	87594	61300	07295
40505	09229	24980	59761	45153	57512	18406	27536	05346
79224	85810	92513	73546	14167	83473	44894	53549	57446
61807	38016	45393	91701	79850	88652	14896	88592	05949
73314	98068	93999	56272	43089	97613	11706	51357	65909
10399	80037	55249	43341	54623	76179	53169	11140	23135
44005	85376	02274	57083	03940	53334	58580	69945	29328
62551	77972	27568	33842	11507	54004	98189	53224	85170
89870	33144	95185	04287	12344	26855	56134	70095	33017
38064	60349	39462	88148	60223	61445	96661	37028	29793
41183	86113	17538	29737	32219	94096	02261	44932	71075
06348	50027	24858	16514	61533	39759	19598	19445	02754
59863	43931	71839	42813	34635	35698	42733	10774	33778
69508	05703	99300	25386	26672	86018	89304	10368	95866
73115	85514	56667	78673	70122	62977	71363	04736	60481
53978	72387	41891	47167	83751	57904	48467	61347	20439
08864	12144	90846	20236	79678	04474	29702	17689	88279

Appendix C – Acadia National Park Video Data Protocols

Data Collection Protocol
(Developed by Dr. Jeff Marion)

Introduction

Mountain summits are popular destinations for hikers and mountaineers. Visitors begin their summit hikes by ascending lower forested mountain slopes on designated trails that can be designed and maintained to sustain traffic with minimal impact. However, hikers in non-forested summit settings can and do leave designated trails to follow informal (visitor-created) trails or to hike off-trail. Off-trail hiking in summit areas often creates numerous informal trails and off-trail trampling impacts to alpine and sub-alpine vegetation and summit soils. Informal trails often follow steep fall-line alignments that allow rapid soil loss unless substrates are predominantly rock. Severe growing conditions (cold, ice, wind) and thin soils in summit environments support sensitive sub-alpine and alpine plant communities that can include globally to locally rare plants and animals. Furthermore, while vegetation in summit areas can be rapidly lost from trampling, recovery is often prevented by the short growing season, unfavorable conditions, and even small amounts of continued trampling. Once exposed, thin summit soils, which developed over thousands of years, are highly vulnerable to erosion from wind, rain, and snowmelt runoff.

Research and management experience suggest a number of effective strategies for protecting summit vegetation and soils (Cole et al. 1987; Hammitt & Cole 1998; Leung & Marion 1999, 2000). One of the more effective strategies is to modify the location of use, for example, concentrating traffic to a limited number of designated trails to limit the areal extent of impact in summit areas. An opposite approach is to disperse traffic sufficiently to avoid or minimize trampling impacts. Additionally, facility designs and information can encourage traffic on impact-resistant substrates and discourage traffic in areas that are most sensitive to trampling. Other applicable strategies are to increase the resistance of the resource and alter visitor behavior. For example, managers can design, construct and maintain trails that limit impact through sustainable designs, select or construct resistant tread surfaces, and manage visitors to discourage off-trail hiking. Visitors can choose to remain on designated formal trails or impact-resistant informal trails, or if they hike off-trail, they can select and use impact-resistant routes and substrates. Finally, managers can limit visitation to reduce impact, prohibit or discourage higher impact forms of visitation or behaviors, or restrict/discourage use during times when conditions are susceptible to impacts.

Management success in implementing these strategies in summit environments is varied and can be challenging. On many summits, use continues to be largely unregulated or managers have designated summit trails originally created by the earliest visitors. The trails generally follow the most accessible direct fall-line alignments, often with exceptionally steep grades. Such alignments are challenging to hike and vegetation and soil loss occur rapidly, though summit environments are generally very rocky and vegetation and soils may be rare. Attempts to correct these deficiencies by constructing impact resistant side-hill alignments may be unsuccessful due to topographic constraints or because visitors may choose a more direct route. Side-hill trails are preferred in forested settings, but the absence of trees in summit areas allows visitors to see and travel a variety of routes more directly to their destination. A relatively effective compromise practice has been to employ direct routes that attempt to avoid patches of soil and vegetation, and concentrate traffic on resistant rock arranged to facilitate safer travel.

Many managers have also sought to discourage use of informal (visitor-created) routes and off-trail "cross-country" routes to protect vegetation and soils. For example, managers commonly employ *Leave No Trace* educational messages that encourage visitors to travel on durable surfaces, particularly the treads of formal trails and bare rock surfaces, and to avoid stepping on vegetation and soil. Further research is needed to evaluate the efficacy of these efforts, particularly the extent to which off-trail visitors actually avoid stepping on vegetation. Finally, few managers have considered or successfully applied dispersal strategies, or sought to reduce total visitation or use during sensitive times, like during snowmelt or the flowering season.

In summary, management experience has generally revealed that a containment strategy emphasizing use of formal trails is the preferred strategy when visitation is moderate to high and resource sensitivity is low to moderate. Many managers discourage but do not prohibit hiking off of formal trails, and the number of visitors who do so is highly variable. To the extent that summit visitors do not need to travel off designated trails to achieve a high quality experiences, managers would prefer to minimize resource impacts by discouraging off-trail hiking. A wide variety of site management and educational practices exist to accomplish this objective. Site management practices include the designation of formal trails, ensuring adequate tread designs and construction to attract and facilitate their use, trail marking (e.g., cairns, paint blazes) and tread definition (e.g., coping stones, scree walls) to identify the route and treads, and occasionally taller scree walls or fencing to constrain traffic in specific locations. Educational practices include messages that discourage off-trail traffic communicated through printed media and posted on signs or verbally through visitor center staff, rangers, or trail stewards.

The purpose of this research is to develop and test alternative best-management practices designed to limit summit area visitor impacts by discouraging hiking away from designated trails. Through collaboration with Acadia National Park staff, which sponsored this research, Gorham Mountain was selected as the study area. Gorham is a popular backcountry mountain summit that receives approximately 400-600 visitors per day during the summer season. The Gorham Mountain trail is the only trail over the summit and it is marked by Bates-style rock cairns and paint blazes to help visitors navigate and remain on-trail. However, pilot testing observational work conducted by park staff in 2007 revealed 223 observed instances of off-trail traffic among 245 visitors who traveled a section of trail just below the summit, including 56 "near-trail" excursions and 167 more distant excursions. Numerous reasons for off-trail traffic exist, including the need to pass other hikers, insufficient marking or attention to marking, desire to explore or select a personal route, blue-berry picking, and photography. Visitors may also not know about the sensitive nature of summit plants and soils or that park policies discourage off-trail traffic. As a result, there is both a challenge and opportunity to improve protection of resources along the trail in a way that is minimally obtrusive to the recreation experience through the selection of effective site management and educational practices.

Literature Review

This research is informed by previous studies that have examined the efficacy of management practices applied in summit environments. Efficacy studies conducted in non-summit settings were also examined (as reviewed by Marion and Reid 2007) but are not presented here. Doucette and Kimball (1990) evaluated the construction of scree walls to create trail borders on Franconia Ridge in NH. Scree walls reduced mean tread width from 3.6 to 2.1 meters and they allowed significant recover of adjacent off-trail vegetation. A survey also found that 87% of visitors thought that the scree walls were effective and 80% found them unobtrusive. Taylor (1981) found that scree walls contributed in preventing 90% of hikers from entering rare plant habitat along a trail on Mt. Washington. Reilly (1992) evaluated the efficacy of educational programs on Mt. Mansfield, Camels Hump and Smugglers' Notch in Vermont and documented problems with visitor inattentiveness to signs, poor trail marking, and poor visitor education regarding the existence of rare and sensitive summit area plants.

An observational study on Acadia National Park's road accessible and highly visited Cadillac Mountain by Turner and Wilbur (2001) found that signs asking visitors to step only on rocks were relatively ineffective and that visitors did not readily distinguish between a paved formal trail and unpaved informal trails. Single barriers designed to discourage access to informal trails were often circumvented while continuous barriers and exclosures were far more effective. Jacobi (2003) evaluated the efficacy of educational signs designed to reduce visitor alterations to 32 cairns along the Gorham Mountain Trail. The signs reduced alterations to cairns from 62% to 43%, though results were not statistically significant. The most relevant study was conducted on Cadillac Mountain (Park et al., 2008) to evaluate the efficacy of educational signs, personal communication, and fencing in deterring off-trail traffic. Observation of visitors revealed that trailhead signs and personal communication (with tour bus drivers) were relatively ineffective in reducing off-trail hiking. In one educational treatment visitors were asked to "Stay on the Paved Trail or Bedrock" yet observations revealed no statistical effect in comparison to other treatments asking visitors to remain on the paved trail. Observations of off-trail hikers found that 72.5% did not evidence any visible efforts to avoid trampling summit vegetation or soils (i.e., taking pains to remain on durable bare bedrock). These findings are partially explained by trailhead sign observations revealing that only 30-46% of visitors stopped to read the trailhead signs during the treatments. More substantial success was documented when trailhead signs were combined with symbolic prompter signs placed along the trail, and when low symbolic fencing was installed along trail borders. These actions significantly reduced off-trail hiking from 74% to 24.3% and 1.2%, respectively.

These studies from Acadia National Park's Cadillac Mountain reveal that intensive visitor use and associated impacts can be adequately managed with relatively direct measures, such as prompter signs posted on each informal trail intended for closure, and fencing. Indirect measures such as trailhead educational signs were relatively ineffective in discouraging off-trail hiking. However, a visitor survey conducted as part of the recent Cadillac study also found that when visitors are educated about the impacts of their activities, they are generally willing to accept more direct actions to protect natural resources (Park et al. 2008). This study seeks to extend this research to backcountry settings, where many of the same problems exist but where direct management actions and visually obvious and artificial indirect site management actions (e.g., coping stone trail borders) may be viewed as less appropriate.

Methods

This study will take an approach similar to the one used at Cadillac's summit to evaluate various means of keeping visitors on formal trails that traverse backcountry summits through the use of improved educational signs, trail blazing, border rocks, and fencing. The study will examine the relative efficacy of these educational and site management options along a roughly 75 yard section of the Gorham Mountain Trail slightly below the mountain's summit.

In evaluating treatment options we considered both management traditions within the park and the acceptability and appropriateness of each treatment option. For example, past experience in Acadia NP indicate that rock cairns and paint blazed on tread rock surfaces are the most effective means of marking designated trails in summit environments. Paint blazes are a newer and more efficient option that avoids the higher installation and maintenance work and potential resource impacts associated with rock collection for cairns. However, cairns are a historic and traditional trail marking method on summits that are also important to visitor safety when snow cover hides paint blazes. Additional comments regarding the considerations involved with the selection of individual treatment options are included for each proposed study treatment described below.

Treatments

Control/Baseline – This is the "existing condition" or baseline treatment that will retain existing cairns, paint-blazes, and trailhead signs (w/border rocks removed). *Comments:* This is the "control" treatment, against which the efficacies of the following interventions will be compared. In all treatments where cairns are included, observation tallies will be made to document the extent to which visitors move rocks that affect cairns.

Blazing – This treatment applies additional paint-blazes along the tread to clearly mark the intended route (w/cairns removed). *Comments:* Many visitors, particularly in rocky terrain, keep their eyes on the trail about 5-20 ft in front of them. Cairns and blazes more distant than this may not be seen so visitors make route decisions based on visible disturbance to vegetation, soil, and rock. Off-trail hiking may then result if there are numerous disturbed paths or routes to choose from that are not marked in close proximity by paint blazes or cairns. This intervention will remove such uncertainty, providing a very clearly marked route. Cairns will be removed (as requested by maintenance staff) to evaluate the paint blazing option that may become necessary if budget cuts further limit trail maintenance capabilities (visitor rock-moving requires constant maintenance). A method for making the paint blazes temporary (water-based paint w/wire brushing, or blue duck tape) is needed as this treatment will be removed from most other treatments.

Educational Signs – This treatment adds educational signs (see proposed text below) at trailside locations where the summit trail emerges from the woods (one on each side of the summit). These signs will be approximately 1.5 x 2 ft in size and positioned close to the trail and oriented so that they are easily read by hikers traveling uphill. Prompter signs (3.5x5") mounted to 2x2" posts about 8" off the ground will also be installed behind the fence at 2-3 locations on each side to clarify management intent discouraging off-trail traffic. Additional paint blazes will also be included in this treatment so that the intended formal trail is clearly identified.

***Leave No Trace* of your Summit Visit**

Your Footsteps Damage Fragile Plants & Soils

Please:

Do Not Leave Paint-Blazed Trails

Do Not Move Rocks

Comments: Management interventions designed to mark designated trails and discourage off-trail hiking can fail because visitors are unaware that summit plants and soils are fragile or that managers seek to protect these resources by discouraging off-trail hiking. Furthermore, visitors often fail to distinguish between formal and informal trails. Finally, visitors who remove rocks from cairns, trailside borders (copers or scree walls) create a tremendous burden for land managers and volunteers that can lessen the efficacy of those actions. The trailside approach signs address these concerns and uses wording based on social science theory and found to have the highest efficacy in previous studies. Using the phrase *Leave No Trace* ties the message to a broader national education program and communicates an intended personal outcome. The NPS and LNT logos will also be included on the sign to bolster the authority to the message. Prompter signs within the study area will reinforce the approach sign message.

Coping Stones, 6 ft – This treatment will add pairs of coping stones spaced 6 ft apart along both sides of the trail throughout the study area. *Comments:* Unlike forested settings, rocky mountain summits generally lack visual vegetative cues that mark trail borders or constrain traffic to a single narrow tread. Furthermore, summit trails are often oriented along the fall line, which readily permits the lateral spread of traffic, unlike side-hill trails where adjacent topography limits off-trail traffic. Because hikers can move off-trail anywhere in such environments, a continuous trail border treatment is likely to be more effective than treatments applied only at informal trail junctions. However, to block use of intersecting informal trails a short continuous row of coping stones will be placed to clearly signify the intent to block access and use of these non-designated routes. Viewed obliquely, widely spaced coping stones may be able to convey a visually obvious trail border while minimizing construction effort and the resource impact of rock collection. To prevent alteration/removal by visitors, coping stones should be as large as is practical. Rocks used in this study will be collected from the massive summit cairn. Potential negatives are the work and impact associated with relocating a sufficient number of rocks and maintenance work if rocks are frequently moved by visitors. Observation tallies will be conducted to document the latter.

Low Scree Wall – This treatment will add a continuous row of border stones along both sides of the trail for as long a section as is feasible (e.g., 50 ft). Logs could be used along the lower half of the treated section in place of rocks to evaluate which are more effective and receive less alteration by visitors. *Comments:* This option provides the most clearly defined trail borders and presents visitors with a low physical barrier of rocks or logs. Blockage of informal trails will consist of short sections of scree wall that are 2-3 stones tall. Potential negatives are the work and impact associated with relocating a sufficient number of rocks and maintenance work if rocks are frequently moved by visitors. Observation tallies will be conducted to document the latter.

Fencing – This treatment will add low (1.5 ft tall) rope fencing strung through 2x2" wooden posts along both sides of the same section of trail treated by the low scree wall. *Comments:* The option requires considerably less effort and resource impact to install and may suffer less alteration from visitors than border stones and scree walls.

Integrated – This treatment will integrate educational and site management actions, including coping stones spaced at 6 ft, educational approach signs, and prompter signs. *Comments:* This treatment employs rock borders to mark the formal trail and its boundaries, while including effective communication of management intent and rationale. Therefore it represents a possible "maximum acceptable combination" of actions that should be reasonably effective and easily applied and maintained.

Summary of management actions by treatment. Note that to the extent possible, treatments will be randomly selected to determine their order of application (some restrictions necessary to minimize installation work).

Treatments	Management Actions						
	Educational Signs	Additional Paint Blazes	Cairns	Coping Stones	Scree Wall	Trailside Fencing	Prompter Signs
Control (baseline)	No	No	Yes	No	No	No	No
Blazing	No	Yes	No	No	No	No	No
Educational Signs	Yes	Yes	Yes	No	No	No	Yes
Coping Stones, 6 ft	No	No	Yes	Yes	No	No	No
Low Scree Wall	No	No	Yes	No	Yes	No	No
Symbolic Fencing	No	No	Yes	No	No	Yes	No
Integrated	Yes	No	Yes	Yes	No	No	Yes

Evaluation Method

Evaluation will be conducted with video recordings collected by three small wire-less video cameras mounted approximately 25-75 feet from the trail to the upper trunks of fir trees. The cameras will be concealed by attaching small pieces of fir branches. The cameras will have slightly overlapping view sheds of the study area, approximately 50-75 yards of trail including adjacent foreground and background areas where off-trail hiking is expected to occur. An additional camera may also be placed to view visitors as they pass the closest educational treatment sign so that the length of time hikers devote to reading the sign can be assessed. This may also enable analyses of an individual's attention to sign to their subsequent behavior regarding on- or off-trail behavior within the study area.

The cameras will either be placed far enough from the trail so that individual's faces and identity cannot be determined. Camera images are transmitted to a DVR recorder for storage on a high capacity hard disk with DVD back-up capability. The DVR will be placed in a locked plastic case also containing a deep cycle gel cell battery, inverter, and wireless antennae located in deep vegetation cover below the summit ridge several hundred feet away. A well-concealed area showing no evidence of visitor traffic will be selected and a note attached to the case will describe its use as part of a scientific study that should not be disturbed. The DVR unit will be visited daily in an unobtrusive manner to download research data and check/replace all batteries. Daily evaluations of video data will ensure that the cameras and recorder are working properly.

Recorded images will be evaluated on a computer screen at a later time. A superimposed graphic overlay for the computer screen will be prepared with colored bands corresponding to trail borders to clarify when visitors step off-trail. These borders will be created based on the placement of coping stones in treatment 5 and applied to all other treatments. A second band marked approximately 3 feet from the trail border band will be used to distinguish between visitors who inadvertently stray from the trail from those who intentionally travel further off-trail. Both rates will be tallied for each study treatment. The number of incidents of visitors tampering with cairn and coping stones will also be tallied by treatment to evaluate the efficacy of the educational sign.

The use of video and DVR technology allows for efficient lab-based analyses and reduces the need for research staff to monitor the research sites continually in person. This technology allows for a substantial increase in the sample size for each treatment, particularly during times of lower use. They will also substantially reduce personnel time and ensure that visitors act in a natural manner. In addition, this approach eliminates observer contact with the visitors in a more remote backcountry study area where unobtrusive observation can be difficult to achieve successfully.

Research will be conducted for approximately four weeks during the July/August use season when visitor use of this trail is at its highest (400-600 visitors/day). This schedule allows for up to 3-4 days per treatment and includes flexible time for inclement weather, ensuring that the research team achieves adequate sample sizes to statistically analyze treatment effects. We expect to obtain a minimum of 800 visitors observed per treatment. A trail counter located on the trail will be checked daily to evaluate when a given treatment can be discontinued and changed to the next treatment.

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Video Transcription Protocol

The purpose of this research is to develop and test alternative best-management practices designed to limit summit area visitor impacts by discouraging hiking away from designated trails. Through collaboration with Acadia National Park staff, which sponsored this research, Gorham Mountain was selected as the study area. Gorham is a popular backcountry mountain summit that receives approximately 400-600 visitors per day during the summer season. The Gorham Mountain trail is the only trail over the summit and it is marked by Bates-style rock cairns and paint blazes to help visitors navigate and remain on-trail. Off-trail hiking is a concern because the subalpine vegetation is relatively fragile and recovery rates are low due to the shallow dry soils. Numerous reasons for off-trail traffic exist, including the need to pass other hikers, insufficient marking or attention to marking, desire to explore or select a personal route, blue-berry picking, and vistas/photography. Visitors may also not know about the sensitive nature of summit plants and soils or that park policies discourage off-trail traffic. As a result, there is both a challenge and opportunity to improve protection of resources along the trail in a way that is minimally obtrusive to the recreation experience through the selection of effective site management and educational practices.

Observation protocols: Define the study trail boundaries by watching hikers to determine which areas can be consistently and accurately observed. Define the upper and lower boundaries on the basis of where the feet of hikers are readily observable. Also check the transitions between camera views to see if any trail segments need to be omitted. Draw these boundaries onto the paper upon which the video images are projected. Also, draw onto the paper some outlines of several boulders within each camera's view shed so that if the projector or paper is moved they can be relocated accurately. Locate the video sections where field staff walked the trail boundaries and draw two lines on the paper for each side of the trail based on points defined the by outermost foot steps of the trail border walker and the outermost footsteps of the outermost walker (6 ft apart).

Start a new form for each hour of video observed. Record the video day/time info for when you start and stop each observation period. Record the weather and observers at the end of the observation period. Never exceed a 4x speed when watching for new hikers to appear and never exceed a 2x speed when evaluating hikers for off-trail behavior. Count only hikers/joggers, not children being carried. During observations record one tally for each uphill hiker and one tally for each downhill hiker and sum the totals and record at the top of the form at the end of the observation period (these tallies can be recorded on other paper and the totals transferred). These totals are very important as they are used to calculate the off-trail rates that we are testing in this study. During observations record an "off-trail" tally for each hiker within the study segment for each time a hiker makes a decision to walk off-trail. Two types of off-trail hiking will be tallied: Near (w/in about 6 ft of trail border) and Far (>6 from trail border). Off-trail hiking is defined as when both feet fall on ground that is beyond (not on) the trail border line or the outer trail corridor line. Record all tallies separately for the two sections of trail (the lower section not involved in border rocks and the upper section where border rocks are applied). Ignore hikers who enter the study area off-trail until they get on the formal trail then record off-trail hiking decisions after this time. Do record hikers who go off-trail between the viewsheds of Cam 1&2 and Cam 2&3. Always record a near tally for every far tally, even for those hikers who go off-trail between Cam 1&2 and Cam 2&3. See field form at the end of these procedures. Make a note of all edits needed to improve/refine these procedures.

Treatments

Control/Baseline – This is the "existing condition" or baseline treatment that retained existing cairns, paint-blazes, and trailhead signs (border rocks were removed). *Comments:* This is the "control" treatment, against which the efficacies of the management interventions will be compared. There were 10 paint blazes present during the control period. In all treatments where cairns are included, observation tallies will be made to document the extent to which visitors move rocks that affect cairns. There were 10 paint blazes present during this period. Dates: 7/17 @ 12:14am to 7/21 @ 5:26pm (several gaps in video coverage due to DVR backups).

Observation protocols: No special protocols for this treatment.

Blazing – This treatment applies additional paint-blazes along the tread to clearly mark the intended route (w/cairns removed). *Comments:* Many visitors, particularly in rocky terrain, keep their eyes on the trail about 5-20 ft in front of them. Cairns and blazes more distant than this may not be seen so visitors make route decisions based on visible disturbance to vegetation, soil, and rock. Off-trail hiking may then result if there are numerous disturbed paths or routes to choose from that are not marked in close proximity by paint blazes or cairns. This intervention will remove such uncertainty, providing a very clearly marked route. Cairns will be removed (as requested by maintenance staff) to evaluate the paint blazing option that may become necessary if budget cuts further limit trail maintenance capabilities (visitor rock-moving requires constant maintenance). Additional blazes will be added by using strips of tape the same color as the paint blazes so that additional blazes can be removed for subsequent treatments.

Observation protocols: No special protocols for this treatment.

Educational Signs – This treatment adds educational signs (see large photo below) at trailside locations at both ends of the study trail segment. These signs were positioned close to the trail and oriented so that they are easily read by hikers. Additional blazes (tape strips) were placed to clearly define the intended trail, a total of 13 within the observation area. Six additional tape blazes were placed between the study area and the summit to encourage visitors to enter the study area on the formal trail. Prompter signs (see small photo below) mounted to 4x4 blocks of wood were placed at 10 visible off-trail locations to clarify management intent that off-trail travel is discouraged. Two additional prompters were placed between the study area and the summit.

Comments: Management interventions designed to mark designated trails and discourage off-trail hiking can fail because visitors are unaware that summit plants and soils are fragile or that managers seek to protect these resources by discouraging off-trail hiking. Furthermore, visitors often fail to distinguish between formal and informal trails. Finally, visitors who remove rocks from cairns, trailside borders (copers or scree walls) create a tremendous burden for land managers and volunteers that can lessen the efficacy of those actions. The trailside approach signs address these concerns and uses wording based on social science theory and found to have the highest efficacy in previous studies. Using the phrase *Leave No Trace* ties the message to a broader national

education program and communicates an intended personal outcome. The NPS logo included on the sign bolsters the official authority of the message. Prompter signs within the study area reinforce the approach sign messages.

Dates: 7/22 @ 9am to 7/23 @ 6pm.

Observation protocols: Record each hiker's attention to the study sign as: No apparent notice - hiker went past the sign w/no apparent long glance or slowing in the rate of travel, Glance – hiker clearly glanced at the sign for 1 to 2 seconds as indicated by a brief pause in hiking with the head oriented in direction of the sign, Read – hiker clearly stopped to read the sign for 3 or more seconds. For this treatment all other tallies will be made with the first letters of their sign attention evaluation: n (no), g (glance), or r (read).

Coping Stones, 6 ft – This treatment adds pairs of coping stones spaced 6 ft apart along both sides of the trail throughout the study area. *Comments:* Unlike forested settings, rocky mountain summits generally lack visual vegetative cues that mark trail borders or constrain traffic to a single narrow tread. Furthermore, summit trails are often oriented along the fall line, which readily permits the lateral spread of traffic, unlike side-hill trails where adjacent topography limits off-trail traffic. Because hikers can move off-trail anywhere in such environments, a continuous trail border treatment is likely to be more effective than treatments applied only at informal trail junctions. However, to block use of intersecting informal trails a short continuous row of coping stones will be placed to clearly signify the intent to block access and use of these non-designated routes. Viewed obliquely, widely spaced coping stones may be able to convey a visually obvious trail border while minimizing construction effort and the resource impact of rock collection. To prevent alteration/removal by visitors, coping stones should be as large as is practical. Rocks used in this study will be collected from the massive summit cairn. Potential negatives are the work and impact associated with relocating a sufficient number of rocks and maintenance work if rocks are frequently moved by visitors. Observation tallies will be conducted to document the latter.

Observation protocols: No special protocols for this treatment.

Low Scree Wall – This treatment added a continuous row of border stones along both sides of the trail beginning at the upper end and running as far as the rock availability allowed (about 1/3 of the study area?). *Comments:* This option provides the most clearly defined trail borders and presents visitors with a low physical barrier of rocks. Potential negatives are the work and impact associated with relocating a sufficient number of rocks and maintenance work if rocks are frequently moved by visitors. Dates: Installed on 7/24 and taping begun on 7/26 @ 9am to 7/28 @ 6pm

Observation protocols: No special protocols for this treatment.

Fencing – This treatment will add low (1.5 ft tall) rope fencing strung through 2x2" wooden posts along both sides of the same section of trail treated by the low scree wall. *Comments:* The option requires considerably less effort and resource impact to install and may suffer less alteration from visitors than border stones and scree walls.

Observation protocols: No special protocols for this treatment.

Integrated – This treatment will integrate educational and site management actions, including coping stones spaced at 6 ft, educational approach signs, and prompter signs. *Comments:* This treatment employs rock borders to mark the formal trail and its boundaries, while including effective communication of management intent and rationale. Therefore it represents a possible “maximum acceptable combination” of actions that should be reasonably effective and easily applied and maintained.

Observation protocols: Include the attention to sign observations and special tallies for this treatment.

Summary of management actions by treatment. Note that to the extent possible, treatments will be randomly selected to determine their order of application (some restrictions necessary to minimize installation work).

	Management Actions						
Treatments	Educational Signs	Additional Paint Blazes	Cairns	Coping Stones	Scree Wall	Trailside Fencing	Prompter Signs
Control (baseline)	No	No	Yes	No	No	No	No
Blazing	No	Yes	No	No	No	No	No
Educational Signs	Yes	Yes	Yes	No	No	No	Yes
Coping Stones, 6 ft	No	No	Yes	Yes	No	No	No
Low Scree Wall	No	No	Yes	No	Yes	No	No
Symbolic Fencing	No	No	Yes	No	No	Yes	No
Integrated	Yes	No	Yes	Yes	No	No	Yes

Gorcam Observation Form

Camera Date: ________ Time: ______ to Date: ________ Time: ______ Observers: ______________

Totals = Up: __________ Down: __________ Clear, Overcast, Fog Rain: Y / N Windy: Y / N

Near	Far
Cam 2 Up	**Cam 2 Up**
Cam 2 Down	**Cam 2 Down**
Cam 3 Up	**Cam 3 Up**
Cam 3 Down	**Cam 3 Down**
Cam 4 Up	**Cam 4 Up**
Cam 4 Down	**Cam 4 Down**

Gorcam Observation Form

Observation Period = Videotape Date/time: ____________________ to Date/time: ____________________

Observer: _____________________ Treatment in Place: __________________________

Uphill Hikers											
Near Off-Trail Hikers in Upper Border-rock section						Near Off-Trail Hikers in Lower section					
Far Off-Trail Hikers in Upper Border-rock section						Far Off-Trail Hikers in Lower section					
Reasons for Off-trail Hiking[a]											
1:	2:	3:	4:	5:	6:	1:	2:	3:	4:	5:	6:
Rock Movers											
Scree/Border:			Cairn:			Scree/Border:			Cairn:		
Hikers:						Hikers:					
Downhill Hikers											
Near Off-Trail Hikers in Upper Border-rock section						Near Off-Trail Hikers in Lower section					
Far Off-Trail Hikers in Upper Border-rock section						Far Off-Trail Hikers in Lower section					
Reasons for Off-trail Hiking[a]											
1:	2:	3:	4:	5:	6:	1:	2:	3:	4:	5:	6:
Rock Movers											
Scree/Border:			Cairn:			Scree/Border:			Cairn:		
Hikers:						Hikers:					

[a] **Off-trail Hiking Motives (as perceived by observer)**

1=Not paying attention or taking a different route

2=To move past others or allow others to pass (including crowding-related reasons)

3=To access a vista for observation or photos

4=To take a photo (other than at vistas)

5=Nature study: stops to investigate plants, wildlife, or rocks

6=Unknown