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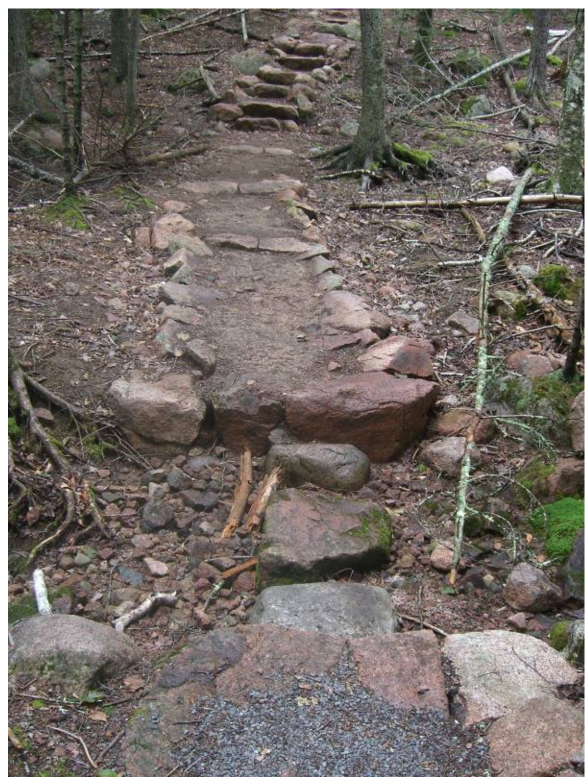
INFORMAL AND FORMAL TRAIL MONITORING PROTOCOLS AND BASELINE CONDITIONS: ACADIA NATIONAL PARK

Final Report



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INFORMAL AND FORMAL TRAIL MONITORING PROTOCOLS AND BASELINE CONDITIONS: ACADIA NATIONAL PARK

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INTRODUCTION

The National Park Service accommodates nearly 300 million visitors per year, visitation that presents managers with substantial challenges. The increasing number of visitors inevitably contributes negative effects to fragile natural and cultural resources and to crowding and conflicts that degrade the quality of visitor experiences. “Providing opportunities for public enjoyment is an important part of the Service’s mission; but recreational activities and other uses may be allowed in parks only to the extent they can take place without causing impairment or derogation of a park’s resources, values, or purposes” (NPS, 2001). This statement, from the National Park Service (NPS) *Management Policies*, provides a strong mandate to guide recreation management decisions in protecting park resources and values at some 388 park units. This policy guidance recognizes the legitimacy of providing opportunities for public enjoyment of parks. However, the *Management Policies* also acknowledge that some resource degradation is an inevitable consequence of visitation and direct managers to “ensure that any adverse impacts are the minimum necessary, unavoidable, cannot be further mitigated, and do not constitute impairment or derogation of park resources and values” (NPS, 2001).

Acadia National Park, with 35,000 acres and 2,227,000 visits in 2009, is one of the most intensively visited National Parks. Such high visitation on a relatively small island land base poses a threat to the protection of nationally significant natural, cultural, and recreational resources. This report presents research on evaluating and mitigating visitor-related impacts to the park’s natural resources while providing critical data to support the application of the visitor experience resource protection framework to establish visitor carrying capacities. Research includes the development and application of trail condition assessment and monitoring protocols to approximately 120 miles of formal (designated) trails on Mount Desert Island, development and refinement of procedures for a GPS-based inventory of informal (visitor-created) trails, an inventory of the extent of trampling impacts and the success of area closures on soils and vegetation at the summit of Cadillac Mountain, and the experimental application and evaluation of educational and site management actions to reduce selected high-priority trail-related visitor impact problems. This report includes only data from the formal and informal trail monitoring portion of this program of research.

At Acadia National Park, changing visitor use levels and patterns have contributed to an increasing degree of visitor use impacts to natural and cultural resources. To better understand the extent and severity of these resource impacts and identify effective management techniques, the park sponsored this research to develop monitoring protocols, collect baseline data, and identify suggestions for management strategies. The park has adopted the NPS Visitor Experience and Resource Protection (VERP) carrying capacity framework to guide these studies.

Study objectives will focus on the four elements of the VERP framework that can benefit the most from empirical data: 1) developing and refining long-term condition assessment protocols for monitoring conditions along the park’s formal and informal trail system, 2) applying the protocols to collect and summarize baseline data on formal trail resource conditions and impacts, 3) helping to identify potential indicators and standards of quality for formal trail conditions, and

4) conducting relational analyses to inform managers on appropriate and effective trail and visitor management practices.

The basic concept of carrying capacity addresses issues related to the amount of visitation that parks can accommodate and the acceptability of associated degradation to resource and social conditions (Manning 1999, Stankey & Manning 1986, Shelby & Heberlein 1986, Graefe *et al.* 1984). The NPS VERP decision framework (see Figure 1) is designed to guide decisions needed to protect park natural and cultural resources while maintaining the quality of the visitor experiences (National Park Service 1997). Additional legislative and management guidance on carrying capacity decision making is provided in the Justification for Monitoring section.

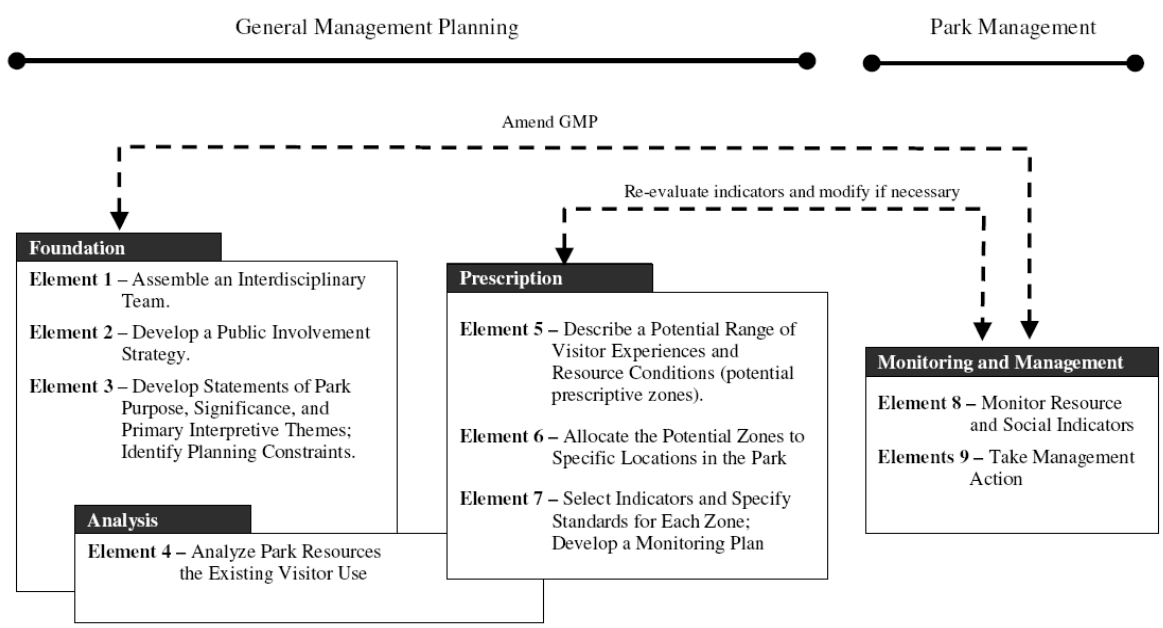


Figure 1. The NPS Visitor Experience and Resource Protection framework used to address carrying capacity decision making.

Assessments of visitor-related resource impacts provided by this study can document baseline conditions for formal trails. These data can also provide partial input to the development of realistic resource condition prescriptions and their allocation through zoning to specific park locations (VERP Elements 5 & 6). Comprehensive assessments of visitor impacts can serve as a core source for selecting appropriate indicators and as a filter for identifying realistic standards. For example, preliminary indicator standards can be compared with baseline data to determine if current conditions exceed proposed standards and if so, to identify the specific locations so that decision makers could visit these sites to judge if they are appropriate.

Research can evaluate alternative visitor impact assessment methods and procedures; select or develop and refine procedures that are scientifically credible, accurate, precise, and efficient; prescribe a reliable monitoring sampling design; and apply the procedures during the first monitoring cycle to collect, analyze and summarize data on baseline conditions. Relational analyses of the collected data can also identify the role and influence of causal factors (e.g., type and amount of use) and non-causal yet influential factors (vegetation or soil type resistance/resilience, topography, site management practices, visitor regulations and educational efforts). Greater insights into the influence of these factors can lead to the selection of more effective management actions.

This report contains a review of the relevant scientific literature describing trail impacts, criteria for selecting appropriate impact indicators, trail impact assessment methods, and a review of the study area and methods employed in this study. The data collected in this study document baseline resource conditions for comparison to future assessments to detect trends in resource conditions or evaluate the effectiveness of management interventions. These data also support the selection of indicators and standards as part of a carrying capacity planning and management decision-making framework. Study implications and suggestions for park planning, management, and monitoring are provided.

JUSTIFICATION FOR MONITORING

Sustaining any type of long-term natural resource monitoring program over time can be exceptionally challenging for agencies due to changing personnel, management priorities, and budgets. This section reviews legislative mandates, management policies and guidelines, carrying capacity, visitor perceptions of recreation resource conditions, and monitoring program capabilities. The purpose of this review is to describe legislative and management intent regarding visitor impact monitoring and its role in balancing visitor use and resource protection objectives. This section is included to assist in justifying implementation of a recreation site and trail monitoring program and to describe its utility to enlist organizational support for sustaining such a program over time.

Legislative mandates challenge managers to develop and implement management policies, strategies, and actions that permit recreation without compromising ecological and aesthetic integrity. Furthermore, managers are frequently forced to engage in this balancing act under the close scrutiny of the public, competing interest groups, and the courts. Managers can no longer afford a wait-and-see attitude or rely on subjective impressions of deterioration in resource conditions. Professional land management increasingly requires the collection and use of scientifically valid research and monitoring data. Such data should describe the nature and severity of visitor impacts and the relationships between controlling visitor use and biophysical factors. These relationships are complex and not always intuitive. A reliable information base is therefore essential to managers seeking to develop, implement, and gauge the success of visitor and resource management programs.

Although numerous reasons for implementing a visitor impact monitoring program are described in the following sections, the actual value of these programs is entirely dependent upon the park staff who manage them. Programs developed with little regard to data quality assurance or operated in isolation from resource protection decision making will be short-lived. In contrast, programs that provide managers with relevant and reliable information necessary for developing and evaluating resource protection actions can be of significant value. Only through the development and implementation of professionally managed and scientifically defensible monitoring programs can we hope to provide legitimate answers to the question, "Are we loving our parks to death?"

Legislative Mandates

Current legislation and agency documents establish mandates for monitoring (Marion 1991). Recent legislative mandates allow managers more latitude to make proactive decisions that can be defended in court if necessary. Managers who make proactive decisions should be prepared to prove the viability of their strategies, or risk public disapproval or even legal action against the agency. Survey and monitoring programs provide the means for such demonstrations.

Agency Organic Act

The National Park Service Organic Act of 1916 (16 *United States Code* (USC) 1) established the Service, directing it to:

> "promote and regulate the use…[of parks]…to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations."

These provisions were supplemented and clarified by the Congress through enactment of the General Authorities Act in 1970, and through a 1978 amendment expanding Redwood National Park (16 USC 1a-1):

> "the protection, management, and administration of these areas shall be conducted in light of the high public value and integrity of the National Park System and shall not be exercised in derogation of the values and purposes for which these various areas have been established…"

Congress intended park visitation to be contingent upon the National Park Service's ability to preserve park environments in an unimpaired condition. However, unimpaired does not mean unaltered or unchanged. Any recreational activity, no matter how infrequent, will cause changes or impacts lasting for some period of time. What constitutes an impaired resource is ultimately a management decision, a judgment. The Organic Act's mandate presents the agency with a management challenge since research demonstrates that resources are inevitably changed by recreational activities, even with infrequent recreation by conscientious visitors (Cole 1982 1995, Leung & Marion 2000). If interpreted overly strictly, the legal mandate of unimpaired preservation may not be achievable, yet it provides a useful goal for managers in balancing these two competing objectives.

More recently, the National Parks Omnibus Management Act of 1998 established a framework for fully integrating natural resource monitoring and other science activities into the management processes of the National Park System. The Act charges the Secretary of the Interior to:

> "develop a program of inventory and monitoring of National Park System resources to establish baseline information and to provide information on the long-term trends in the condition of National Park System resources."

Congress reinforced the message of the National Parks Omnibus Management Act of 1998 in its text of the FY 2000 Appropriations bill:

> "A major part of protecting [park] resources is knowing what they are, where they are, how they interact with their environment and what condition they are in. This involves a serious commitment from the leadership of the National Park Service to insist that the superintendents carry out a systematic, consistent, professional inventory and monitoring program, along with other scientific activities, that is regularly updated to ensure that the Service makes sound resource decisions based on sound scientific data."

Management Policies and Guidelines

Authority to implement congressional legislation is delegated to agencies, which identify and interpret all relevant laws and formulate administrative policies to guide their implementation. A document titled *Management Policies* (NPS 2006) describes these policies to provide more specific direction to management decision making. For example, relative to the need for balancing visitor use and resource impacts, the NPS *Management Policies* state that:

> "The "fundamental purpose" of the national park system, established by the Organic Act and reaffirmed by the General Authorities Act, as amended, begins with a mandate to conserve park resources and values. This mandate is independent of the separate prohibition on impairment, and so applies all the time, with respect to all park resources and values, even when there is no risk that any park resources or values may be impaired. NPS managers must always seek ways to avoid, or to minimize to the greatest degree practicable, adverse impacts on park resources and values.
>
> Congress, recognizing that the enjoyment by future generations of the national parks can be ensured only if the superb quality of park resources and values is left unimpaired, has provided that when there is a conflict between conserving resources and values and providing for enjoyment of them, conservation is to be predominant. This is how courts have consistently interpreted the Organic Act, in decisions that variously describe it as making "resource protection the primary goal" or "resource protection the overarching concern"… (*Section 1.4.3*)
>
> The impairment that is prohibited by the Organic Act and the General Authorities Act is an impact that, in the professional judgment of the responsible NPS manager, would harm the integrity of park resources or values, including the opportunities that otherwise would be present for the enjoyment of those resources or values. Whether an impact meets this definition depends on the particular resources and values that would be affected; the severity, duration, and timing of the impact; the direct and indirect effects of the impact; and the cumulative effects of the impact in question and other impacts. (*Section 1.4.5*)
>
> Impacts may affect park resources or values and still be within the limits of the discretionary authority conferred by the Organic Act. However, negative or adverse environmental impacts are never welcome in national parks, even when they fall far short of causing impairment. For this reason, the Service will not knowingly authorize a park use that would cause negative or adverse impacts unless it has been fully evaluated, appropriate public involvement has been obtained, and a compelling management need is present. In those situations, the Service will ensure that any negative or adverse impacts are the minimum necessary, unavoidable, cannot be further mitigated, and do not constitute impairment of park resources and values." (*Section 8.1*)

Thus, relative to visitor use, park managers must evaluate the types and extents of resource impacts associated with recreational activities, and determine to what extent they constitute impairment or are unacceptable. That is, managers must seek to avoid or limit any form of resource impact, including those judged to fall short of impairment. Visitor impact monitoring programs can assist managers in making objective evaluations of impact acceptability and impairment and in selecting effective impact management practices by providing quantitative documentation of the types and extent of recreation-related impacts to natural resources. Monitoring programs are also explicitly authorized in Section 4.1 of the Management Policies:

> "Natural systems in the national park system, and the human influences upon them, will be monitored to detect change. The Service will use the results of monitoring and research to understand the detected change and to develop appropriate management actions". (*Section 4.1*)
>
> “Further, The Service will:
> - Identify, acquire, and interpret needed inventory, monitoring, and research, including applicable traditional knowledge, to obtain information and data that will help park managers accomplish park management objectives provided for in law and planning documents.
> - Define, assemble, and synthesize comprehensive baseline inventory data describing the natural resources under its stewardship, and identify the processes that influence those resources.
> - Use qualitative and quantitative techniques to monitor key aspects of resources and processes at regular intervals.
> - Analyze the resulting information to detect or predict changes, including interrelationships with visitor carrying capacities, that may require management intervention, and to provide reference points for comparison with other environments and time frames.
> - Use the resulting information to maintain-and, where necessary, restore-the integrity of natural systems" (*Section 4.2.1*).

The National Park Service has implemented a strategy designed to institutionalize natural resource inventory and monitoring on a programmatic basis throughout the agency. A service-wide Inventory & Monitoring Program has been implemented to ensure that park units with significant natural resources possess the resource information needed for effective, science-based managerial decision-making and resource protection. A key component of this effort, known as the NPS Inventory & Monitoring Program, is the organization of park units into 32 ecoregional networks to conduct long-term monitoring for key indicators of change, or “vital signs.” Vital signs are measurable, early warning signals that indicate changes that could impair the long-term health of natural systems. Early detection of potential problems allows park managers to take steps to restore ecological health of park resources before serious damage can happen.

Carrying Capacity Decision Making

Decisions regarding impact acceptability and the selection of actions needed to prevent resource impairment frequently fall into the domain of carrying capacity decision making. The 1978 National Parks and Recreation Act (P.L. 95-625) requires the NPS to determine carrying capacities for each park as part of the process of developing a general management plan. Specifically, amendments to Public Law 91-383 (84 Stat. 824, 1970) require general management plans developed for national park units to include “identification of and implementation commitments for visitor carrying capacities for all areas of the unit” and determination of whether park visitation patterns are consistent with social and ecological carrying capacities. Regulations implementing the National Forest Management Act of 1976 (P.L. 94-588) dictate that, in wilderness management planning, provision be made “for limiting and distributing visitor use of specific areas in accord with periodic estimates of the maximum levels of use that allow natural processes to operate freely and that do not impair the values for which wilderness areas were created.”

The NPS employs the Visitor Experience and Resource Protection (VERP) planning and decision-making framework for formal evaluations of the acceptability of visitor impacts and for establishing carrying capacity limits on visitation (NPS 1997, NPS 2006) (**Error! Reference source not found.**). Visitor impact monitoring programs provide an essential component of such efforts. VERP and other similar frameworks (e.g., Limits of Acceptable Change, LAC), evolved from, and have largely replaced, management approaches based on the more traditional carrying capacity model (Stankey *et al.* 1985). Under these newer frameworks, numerical standards are set for individual biophysical or social condition indicators. These limits define the critical boundary between acceptable and unacceptable change in resource or social conditions, and against which future conditions can be compared through periodic monitoring. VERP is an adaptive management process wherein periodic monitoring is conducted to compare actual conditions to quantitatively defined standards of quality. If standards are exceeded, an evaluation is conducted to identify those factors that managers can effectively manipulate to improve conditions for the indicators with sub-standard (unacceptable) conditions. For example, if a standard for the individual or aggregate size of recreation sites was exceeded, managers might consider implementing one or more site management or educational actions. If the next cycle of monitoring also found sub-standard conditions, more restrictive actions like fencing or area closures would be considered.

Additional guidance on visitor carrying capacity decision-making is provided in the NPS *Management Policies* (2006):

> "Visitor carrying capacity is the type and level of visitor use that can be accommodated while sustaining the desired resource and visitor experience conditions in the park. By identifying and staying within carrying capacities, superintendents can prevent park uses that may unacceptably impact the resources and values for which the parks were established. For all zones, districts, or other logical management divisions within a park, superintendents will identify visitor carrying capacities for managing public use. Superintendents will also identify ways to monitor for, and address, unacceptable impacts to park resources and visitor experiences.
>
> When making decisions about carrying capacity, superintendents must utilize the best available natural and social science and other information, and maintain a comprehensive administrative record relating to their decisions. The decision making process should be based on desired resource conditions and visitor experiences for the area; quality indicators and standards that define the desired resource conditions and visitor experiences; and other factors that will lead to logical conclusions and the protection of park resources and values…
>
> The general management planning process will determine the desired resource and visitor experience conditions that are the foundation for carrying capacity analysis and decision making. If a general management plan is not current or complete, or if more detailed decision making is required, a carrying capacity planning process, such as the Visitor Experience and Resource Protection (VERP) framework, should be applied in an implementation plan or an amendment to an existing plan.
>
> As use changes over time, superintendents must continue to decide if management actions are needed to keep use at acceptable and sustainable levels. If indicators and standards have been prescribed for an impact, the acceptable level is the prescribed standard. If indicators and standards do not exist, the superintendent must determine how much impact can be tolerated before management intervention is required." (*Section 8.2.1*)

Visitor Perceptions of Resource Conditions

Visitors to wildland environments are aware of resource conditions along trails and at recreation sites, just as are managers (Lucas 1979, Marion & Lime 1986, Vaske & others 1982). Legislative mandates set high standards when they direct managers to keep protected natural areas "unimpaired" and human impacts "substantially unnoticeable." Seeing trails and recreation sites, particularly those in degraded condition, reminds visitors that others have preceded them. In remote areas even the presence of trails and recreation sites reduce perceived naturalness and can diminish opportunities for solitude. In accessible and popular areas the proliferation and deterioration of trails and recreation sites present a "soiled" or "used" appearance, in contrast to the ideal of a pristine natural environment (Leung & Marion 2000).

Degraded resource conditions on trails and recreation sites can have significant utilitarian, safety, and experiential consequences for visitors (Leung & Marion 2000). Trails serve a vital transportation function in protected natural areas and their degradation greatly diminishes their utility for visitors and land managers. For example, excessive tread erosion or muddiness can render trails difficult and unpleasant to use. Such conditions can also threaten visitor or packstock safety and prevent or slow rescues, possibly increasing agency liability. Impacts associated with certain types of uses, such as linear rutting from bikes or vehicles or muddy hoof prints from horses, can also exacerbate conflicts between recreationists.

Visitors spend most of their time within protected natural areas on trails and recreation sites, so their perceptions of the area and its naturalness are strongly influenced by trail and site conditions. Visitors are sensitive to overt effects of other visitors (such as the occurrence of litter, horse manure, malicious damage to vegetation) and to visually obtrusive examples of impacts such as tree root exposure, tree felling, and soil erosion. A survey of visitors to four wilderness areas, three in southeastern states and another in Montana, found that littering and human damage to recreation site trees were among the most highly rated indicators affecting the quality of recreational experiences (Roggenbuck *et al.* 1993). Amount of vegetation loss and exposed soil around a recreation site were rated as more important than many social indicators, including number of people seen while hiking and encounters with other groups at recreation sites. Hollenhorst and Gardner (1994) also found vegetation loss and bare ground on recreation sites to be important determinants of satisfaction by wilderness visitors.

Monitoring Program Capabilities

Visitor impact monitoring programs can be of significant value when providing managers with reliable information necessary for establishing and evaluating resource protection policies, strategies, and actions. When implemented properly and with periodic reassessments, these programs produce a database with significant benefits to protected area managers (Figure 2). Data from the first application of impact assessment methods developed for a long-term monitoring program can objectively document the types and extent of recreation-related resource impacts. Such work also provides information needed to select appropriate biophysical indicators and formulate realistic standards, as required in VERP or LAC planning and decision making frameworks.

Reapplication of impact assessment protocols as part of a monitoring program provides an essential mechanism for periodically evaluating resource conditions in relation to standards. Visitor impact monitoring programs provide an objective record of impacts, even though individual managers come and go. A monitoring program can identify and evaluate trends when data are compared between present and past resource assessments. It may detect deteriorating conditions before severe or irreversible changes occur, allowing time to implement corrective actions. Analysis of monitoring data can reveal insights into relationships with causal or non-causal yet influential factors. For example, the trampling and loss of vegetation may be greatly reduced by shifting recreation sites or trails to more resistant and resilient vegetation types instead of implementing more contentious limitations on use. Following the implementation of corrective actions, monitoring programs can evaluate their efficacy.

- Identify and quantify site-specific resource impacts.
- Summarize impacts by environmental or use-related factors to evaluate relationships.
- Aid in setting and monitoring resource conditions standards of quality.
- Evaluate deterioration to suggest potential causes and effective management actions.
- Evaluate the effectiveness of resource protection measures.
- Identify and assign priorities to maintenance needs.

Figure 2. Capabilities of visitor impact monitoring programs.

LITERATURE REVIEW

Two primary issues associated with the development of a visitor impact monitoring program are the selection of indicators that will be monitored and their assessment procedures. Criteria for selecting indicators of change related to recreation sites and trails are reviewed, and prospective indicators and measurement units are presented. Common recreation site and trail impact assessment procedures are also reviewed.

Visitation-Related Resource Impacts

Visitors participating in a diverse array of recreation activities, including hiking, camping, wildlife viewing, biking, and boating, contribute to an equally diverse array of effects on protected natural areas resources, including vegetation, soils, water, and wildlife. The term *impact* is commonly used to denote any undesirable visitor-related change in these resources. This study was restricted to assessments of trampling-related impacts to vegetation and soil along trails.

Trail Impacts

The NPS has applied a wide range of tools and techniques to manage visitor use, including the development of recreation infrastructures that include formal designated trail systems. Well-designed and managed formal trails accommodate intensive visitor traffic by providing durable treads “hardened” to sustain substantial traffic. The provision of formal trails is consistent with a “containment” strategy that minimizes visitor impacts by concentrating traffic on durable tread surfaces that provide access to a variety of park locations (Hammitt & Cole 1998, Marion & Leung 2004). Confining trampling impacts to a limited network of formal trails avoids more widespread degradation that would be caused by less structured patterns of visitor activity and traffic.

Most formal trail systems are designed and maintained to sustain high traffic while minimizing associated environmental impacts. For example, well-designed trails avoid steep grades and “fall line” alignments parallel to the landform grade that are difficult to drain and intercept natural water flows (Marion & Leung 2004, Olive & Marion 2009). When a trail is constructed, the surface vegetation and organic litter are removed, exposing underlying mineral soil that is shaped and compacted into a durable surface for visitor travel. However, exposure of soil on natural surfaced trails can lead to an array of direct and indirect resource impacts, including soil compaction, muddiness, erosion, and trail widening (Hammitt & Cole 1998, Leung & Marion 1996, Tyser & Worley 1992) (Table 1). The compaction of soils decreases soil pore space and water infiltration, which in turn increases muddiness, water runoff and soil erosion. The erosion of soils along trails exposes rocks and plant roots, creating a rutted, uneven tread surface. Eroded soils may smother vegetation or find their way into water bodies, increasing water turbidity and sedimentation impacts to aquatic organisms (Fritz 1993). Visitors seeking to circumvent muddy or badly eroded sections contribute to tread widening and creation of parallel secondary treads, which expand vegetation loss and the aggregate area of trampling disturbance (Marion 1994, Liddle & Greig-Smith 1975).

The creation and use of trails can also directly degrade and fragment wildlife habitats, and the presence of trail users may disrupt essential wildlife activities such as feeding, reproduction and the raising of young (Knight & Cole 1995). For example, Miller and others (1998) found decreased presence of nesting birds near trails in grassland ecosystems. Trails can alter hydrology by intercepting and channeling surface water (Sutherland 2001), and fragment the landscape with potential barriers to flora and some small fauna (Leung 2002, 2007). Finally, visitors and livestock can also introduce and transport non-native plant species along trails, some of which may out-compete undisturbed native vegetation and migrate away from trails (Benninger-Truax *et al.* 1992, Adkison & Jackson 1996, Bhuju & Ohsawa 1998, Potito & Beatty 2005, Hill & Pickering 2006)

Table 1. Direct and indirect effects of recreational trampling on soils and vegetation.

Effects	**Vegetation**	**Soil**
Direct	Reduced height/vigor Loss of ground vegetation, shrubs and trees Introduction of non-native vegetation	Loss of organic litter Soil exposure and compaction Soil erosion
Indirect	Altered composition – shift to trampling resistant or non-native species Altered microclimate	Reduced soil pore space and moisture, increased soil temperature Increased water runoff Reduced soil fauna

Formal trails are a core component of park infrastructure that influence travel patterns and visitor experiences. Well-designed trail networks provide enjoyable recreation experiences for a wide variety of users, allow access to many points of interest within protected areas, and protect the majority of park land from trampling damage. When formal trail networks fail to provide visitors the access and experiences they desire, visitors frequently venture "off-trail" to reach locations not accessible by formal trails. Even relatively low levels of informal trail traffic can wear down vegetation and organic litter to create visible informal (visitor-created) trail networks (Weaver & Dale 1978, Thurston & Reader 2001). The trampling disturbance from off-trail hiking can alter the appearance and composition of vegetation by reducing vegetation height and favoring trampling resistant species. The loss of tree and shrub cover can increase sunlight exposure, which promotes further changes in composition by favoring shade-intolerant plant species (Hammitt & Cole 1998, Leung & Marion 2000).

Trail Management

Several studies show that proper trail design and construction principles minimize adverse impacts to natural resources and reduce the need for trail maintenance (Leung & Marion 1996, Marion & Leung 2004, Marion 2006, Olive & Marion 2009). The source of many forms of degradation along formal trails can be related to poor design attributes such as steep grades, alignments close to the fall line (parallel to landform aspect), or to locations on perennially wet soils. Some formal trails were originally created by visitors or individuals who lacked trail design expertise or were directed by objectives in conflict with resource protection goals (Marion & Leung 2004). Well-designed trails require periodic maintenance, which can be challenging to sustain under conditions of declining agency budgets. Even well-designed and managed trails are susceptible to the many forms of degradation when subjected to high use or to high-impact behaviors or types of use (e.g., horse riding and motorized uses).

Common knowledge assumes that informal trails are less “sustainable” than their formal trail counterparts, because of the lack of professional design and construction associated with their creation. Visual observation and research also suggests that visitors traveling off-trail often take the shortest path, cutting switchbacks or directly ascending slopes (Cole 1993), or the path of least resistance, avoiding dense vegetation or challenging terrain (Bayfield 1973). Finally, common knowledge assumes that off-trail hikers do not generally recognize or attempt to avoid sensitive resources (e.g., rare fauna/flora habitats), or select routes that reflect the principles of sustainable trail design (e.g., side-hill alignments) (Marion & Leung 2004).

The development, deterioration and proliferation of informal trails in protected areas can be a vexing management issue for land managers. Traveling off-trail is an often desired practice to engage in activities such as nature study, photography or berry picking. Unfortunately, management experience reveals that informal trail systems are frequently poorly designed, including “shortest distance” routing with steep grades and fall-line alignments. Such routes are rarely sustainable under heavy traffic and subsequent resource degradation is often severe. Creation of multiple routes to common destinations is another frequent problem, resulting in “avoidable” impacts such as unnecessary vegetation/soil loss and fragmentation of flora/fauna habitats.

Once created, managers have found it difficult to deter their use and even when successful, their recovery requires long periods of time (Grabherr 1982, Cole 1990, Boucher *et al.* 1991, Roovers *et al.* 2005). Restoration work can hasten recovery but is expensive. Informal trails are particularly problematic because they become more visually obvious as they form, acting as a “releasor cue” that draws even more visitors off formal trails (Roggenbuck 1992, Brooks 2003). Informal trails are often indistinguishable from formal trails, except for formal trail blazes or markings.

Previous research has investigated the deterrence of off-trail hiking through educational messages (Johnson & Swearingen 1992) and site management (Matheny 1979; Johnson *et al.* 1987, Sutter *et al.* 1993, Park *et al.* 2008). Informal trail proliferation and resource impact is a problem across all types of protected natural areas as shown by research and monitoring studies conducted around the globe (Grabherr 1982, Cole 1990, Ferris *et al.* 1993, Marion & Cahill 2004, Manning *et al.* 2006, Marion & Hockett 2006, Wood *et al.* 2006). However, few studies have extensively mapped or investigated the resource impacts of informal trail networks within protected natural areas (Cole *et al.* 1997, Leung 2002, Marion & Hockett 2006, Leung 2007), although several have collected informal trail counts in conjunction with campsite, recreation site, or formal trail inventories (Marion 1994, Leung & Marion 1999c, Dixon *et al.* 2004, Marion & Cahill 2004, Wood *et al.* 2006).

Indicators and Selection Criteria

Indicators are measurable physical, ecological, or social variables used to track trends in conditions caused by human activity so that progress toward goals and desired conditions can be assessed. An indicator is any setting element that changes in response to a process or activity of interest (Merigliano 1990). An indicator's condition provides a gauge of how recreation has changed a setting. Comparison to management objectives or indicator standards reveals the acceptability of any resource changes. Indicators provide a means for restricting information collection and analysis to the most essential elements needed to answer management questions. Examples of questions related to trails include:

Are visitors experiencing an environment where the evidence of human activity is substantially unnoticeable?

Are trail numbers and conditions acceptable given each management zone’s objectives and desired conditions?

Are visitor and trail management practices effective in minimizing the establishment of informal trails or degradation in formal and informal trails?

Before a monitoring program can be developed, appropriate resource indicators must be selected. A single, direct measurement of a trail’s condition is inappropriate because the overall condition is an aggregate of many components. Typically, then, monitoring evaluates various soil, vegetation, or aesthetic elements of a trail that serve as indicators of that facility’s condition. Cole (1989), Marion (1991) and Merigliano (1990) review criteria for the selection of indicators (Table 2), which are summarized here. Management information needs, reflected by the management questions such as the examples above, guide the initial selection of indicators.

Preferred indicators should reflect attributes that have ecological and/or aesthetic significance. Indicator measures should primarily reflect changes caused by the recreational activity of interest. For example, measures of soil loss related to trail construction would be inappropriate. Indicators should be measurable, preferably at an interval or ratio scale where the distances between numeric values are meaningful, i.e. a trail that is 36 inches wide it twice the width as a trail with an 18 inch width. In comparison, a categorical ratings system based on subjective assessments rather than quantitative measures provides data at an ordinal scale. Distance between numeric values are not meaningful so computing an average or using them in statistical analyses or testing is not appropriate.

Table 2. Criteria for selecting indicators of resource condition.

Criteria	**Rationale**
Quantitative	Can the indicator be measured?
Relevant	Does the indicator change as a result of the process or activity of interest?
Efficient	Can the measurements be taken by available personnel within existing time and funding constraints?
Reliable	How precise are the measurements? Will different individuals obtain similar data of the same indicator?
Responsive	Will management actions affect the indicator?
Sensitive	Does the indicator act as an early warning, alerting you to deteriorating conditions before unacceptable change occurs?
Integrative	Does the indicator reflect only its condition or is its condition related to that of other, perhaps less feasibly measured, elements?
Significant	Does the indicator reveal relevant environmental or social conditions?
Accurate	Will the measurements be close to the indicator's true condition?
Understandable	Is the indicator understandable to non-professionals?
Low Impact	Can the indicator be measured with minimal impact to the resource or the visitor’s experience?

Adapted from Cole (1989), Marion (1991), Merigliano (1990), O'Connor & Dewling (1986).

Potential indicators of resource condition are numerous and there is great variation in our ability to measure them with *accuracy*, *precision*, and *efficiency*. All assessments are approximations of an indicator's true value; a measurement method is *accurate* if it closely approximates the true value. *Efficiency* refers to the time, expertise, and equipment needed to measure the indicator's condition. Unfortunately, efficient methods often yield inconsistent results when applied by different individuals. A measurement method is *precise* if it consistently approximates a common value when applied independently by many individuals. Accurate measurements correctly describe how much change has occurred; precise measurements permit objective comparisons of change over time (Cole 1989, Marion 1991). Indicator assessment methods should also be considered when selecting indicators. When choosing a method managers must balance accuracy and precision, for each places constraints upon efficiency and cost-effectiveness. For example, recreation site condition assessments range from highly efficient but subjective evaluations (e.g. photographs or condition class ratings), to rapid assessments (ratings based on numeric categories of damaged trees), to time-consuming research-level measurements (quadrat-based vegetation loss assessments). Regardless of the method selected, comprehensive procedural manuals, staff training, and program supervision stressing quality control can improve both accuracy and precision. However, poorly managed monitoring efforts can result in measurement error that confounds data interpretation or even exceeds the magnitude of impact caused by recreational activities.

Some indicators are less appropriate than others. For example, indicators of depreciative behavior, such as tree damage, litter, and fire construction in areas where fires are banned, detract unacceptably from environmental or social conditions. Unfortunately, indicators that reflect depreciative behavior present difficulties for managers because the resource degradation is often attributable to a small number of visitors whose actions may be less responsive to traditional management actions. These, and other indicators that are temporally dynamic, are also difficult to monitor effectively. For example, the number of fire sites and extent of litter and improperly disposed human waste can vary considerably from one week or month to the next.

Preferred Indicators

From these indicator criteria and knowledge of how recreation affects soil, vegetation, and aesthetics, managers select preferred indicators of trail or recreation site conditions. Table 3 includes a listing of commonly employed indicators for assessing resource conditions on trails and recreation sites using measurement-based approaches. Generally a small number of indicators are selected for use in LAC or VERP frameworks. However, that does not preclude monitoring of additional resource condition indicators or from also assessing various inventory indicators. Travel time to the sampling locations is often the most substantial portion of the time budget so assessing a few additional indicators can be negligible. A final consideration is the measurement units employed for reporting results and/or setting standards. Measurement-based approaches permit the most flexibility in this respect.

For trails, the number, length, and density of visitor-created trails, along with tread width, are the most commonly used indicators. Soil loss, the most ecologically significant trail impact, can be assessed at sample points by measuring maximum incision or cross sectional area. Similarly, tread muddiness can be assessed at sample points as a percentage of tread width.

Table 3. Potential indicators of trail conditions and measurement units.

Trail Indicators	Measurement Units
Informal Trails	Length/unit area, % of formal trail length, #/unit length on formal trails
Tread Width	Max. value, value/unit length, running avg./unit length
Maximum Incision	Max. value, value/unit length, running avg./unit length
Cross Sectional Area	Max. value, value/unit length, running avg./unit length
Muddiness	Max. % of tread width, avg. %/unit length, running avg. %/unit length

In summary, managers must consider and integrate a diverse array of issues and criteria in selecting indicators for monitoring impacts on trails. Indicators will rarely score high on all criteria requiring good judgment as well as area-specific field trials and direct experience. Indicators that score high on some criteria but low on others may be retained in some instances or omitted in others. Tradeoffs are also required, such as a necessary reduction in accuracy so that precision and efficiency may be increased.

Types of Trail Impact Assessment Systems

Formal trail surveys provide information for a number of important management needs. The location and lineal extent of formal and informal trails can be documented and monitored. The number, location and efficacy of trail maintenance features, such as water bars and drainage dips, can be assessed. Trail conditions may be assessed to identify the location, type and extent of trail resource impacts. Information on trail conditions can be used to inform the public about trail resources, justify staffing and funding, evaluate the acceptability of existing resource conditions, analyze relationships between trail impacts and contributing factors, identify and select appropriate management actions, and evaluate changes in trail conditions and the effectiveness of implemented actions.

A variety of efficient methods for evaluating trails and their resource conditions have been developed and described in the literature, as reviewed and compared by Coleman (1977), Cole (1983), and Leung and Marion (2000). At the most basic level, a trail inventory may be employed to locate and map trails and to document trail features such as type of use, segment lengths, hiking difficulty, and natural and cultural features. Trail location information can be accurately documented using a Global Positioning System (GPS) device, which can be input to a Geographic Information System (GIS) for display and analysis of trail attributes (Wolper *et al.* 1994, Wing & Shelby 1999).

Trail facility and maintenance assessments provide information on existing or needed trail maintenance features or work. These assessments may be used to develop databases on signs (e.g., location and text), existing facilities (e.g., bridges) and tread features (e.g., water bars, steps, bog bridging). Prescriptive trail maintenance work log assessments have also been developed to describe recommended solutions to existing tread deficiencies, such as installation of water bars and steps or trail rerouting (Birchard & Proudman 2000, Williams & Marion 1992). Data can be summarized to provide cost and staffing estimates and to direct work crews.

Trail condition assessments seek to describe resource conditions and impacts for the purpose of documenting trends in trail conditions, investigating relationships with influential factors, and evaluating standards or the efficacy of corrective management actions. Leung and Marion (2000) provide a classification of alternative trail impact assessment and monitoring methods. Sampling-based approaches employ either systematic point sampling, where tread assessments are conducted at a fixed interval along a trail (Cole 1983, 1991), or stratified point sampling, where sampling varies in accordance with various strata such as level of use or vegetation type (Hall & Kuss 1989). Alternately, census-based approaches employ either sectional evaluations, where tread assessments are made for entire trail sections (Bratton *et al.* 1979), or problem census evaluations, where continuous assessments record every occurrence of predefined impact problems (Cole 1983, Leung & Marion 1999a, Marion 1994). These two approaches of assessment have been combined in an integrative survey (Bayfield & Lloyd 1973). More elaborate and time-consuming methods for accurately characterizing soil loss (Leonard & Whitney 1977) and vegetation changes (Hall & Kuss 1989) have also been developed.

An evaluation by Marion and Leung (2001) concluded that the point sampling method provides more accurate and precise measures of trail characteristics that are continuous or frequent (e.g., tread width or exposed soil). The problem census method is a preferred approach for monitoring trail characteristics that can be easily predefined or are infrequent (e.g., excessive width or secondary treads), particularly when information on the location of specific trail impact problems is needed.

Assessing Informal Trail Networks

A comprehensive review of the literature found very few reported examples of research or monitoring efforts focused on assessing informal trail networks (Marion *et al*. 2006). While informal trails likely occur in nearly every protected area, managers have frequently ignored their presence, limiting monitoring efforts to formal trail systems. Furthermore, conventional trail condition assessment protocols are often difficult to apply to informal trails due to their unique spatial characteristics (Marion & Leung 2001). Informal trail segments are often comparatively numerous, short, and often braided in complex patterns (see Figure 3), creating sampling and assessment difficulties for point sampling or problem assessment methods (Leung & Marion 1999).

However, scientists and managers have recently been focusing greater attention to the impacts of informal trail networks and to developing methods for assessing and monitoring their impacts on protected area resources. Managers seeking to assess informal trails must first consider two categories of attributes: spatial and resource condition. Spatial attributes include the location, arrangement, and lineal extent of informal trails. Resource condition attributes include assessed degradation of vegetation, organic litter, and soils along informal trails.

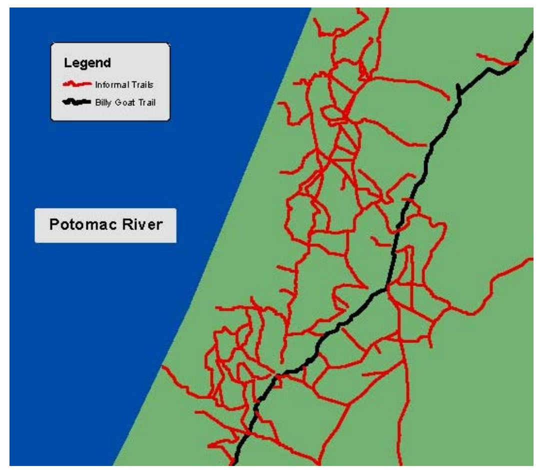


Figure 3. A "spaghetti" map showing the complex network of informal trails branching off the Potomac Gorge's Billy Goat Trail, C&O Canal National Historical Park.

It is possible to assess most spatial attributes using scale-appropriate airborne remote sensing techniques if trails are not under concealing vegetation or when they are readily visible in leaf-off photography (Witztum & Stow 2004). Kaiser and others (2004) applied the best available techniques, including high spatial resolution (0.6m/pixel) digital multi-spectral imagery, digital image processing, and visual image analysis techniques, to detect and delineate new illegal immigrant trails in shrublands along the US-Mexico border. They found that an automated linear feature extraction routine (Feature Analyst in ArcView GIS), followed by manual interpretation, delineation, and editing using false color infrared imagery, yielded the most accurate results. However, this method only resulted in 56% of the GPS surveyed trail locations matching by length, in part due to shielding overhead vegetation.

Extending this work, Cao and others (2007) evaluated three trail monitoring approaches and two types of spectral transformation to aid in locating trails in imagery, procedures designed to evaluate temporal changes in US-Mexico cross-border trail networks. They found that a map-to-image differencing approach was the most sensitive and reliable in detecting new trails, though no ground-based GPS surveys were conducted for comparison. For disturbed areas where the trail networks were extensive, Principal Component Analysis (PCA) of the image was more effective at enhancing new trails. For densely vegetated areas, a Normalized Difference Vegetation Index (NDVI) image yielded more interpreted trails. The authors stress that high quality, well registered, and radiometrically matched multi-temporal image datasets are needed for efficient and reliable trail map updating procedures. Imagery from different years must also be collected at the same phenological time and time of day to minimize errors due to vegetation seasonality and sun angles.

We conclude that these techniques are impractical for most protected area managers due to the substantial expense associated with image acquisition, technician expertise and time, and substantial inaccuracies associated with the methodologies used and concealing vegetation cover. Ground-based Global Positioning System (GPS) surveys are more accurate, use existing staffing and resources, and provide more immediate results. Point-based assessment methods include trailhead and transect surveys. A highly efficient method is to inventory informal trail junctions with protected area roads, trails, or recreation sites, documenting junction locations with a recreation or professional grade GPS, odometer, or measuring wheel (Bacon *et al.* 2006, Marion & Cahill 2006). Alternately, an approach applying transects at fixed intervals within travel zones was developed for Zion National Park to document the number and location of intersecting informal trails (Marion & Hockett 2008a).

Line feature assessment methods provide more comprehensive information on the spatial distribution and lineal extent of informal trail networks. This method requires a GPS set to collect line features (tracks) as field staff walk all informal trails within a management unit. Trail information from the GPS is then input to a Geographic Information System (GIS) for display and analysis of trail attributes (Wolper *et al.* 1994). This commonly applied protocol has been reported in several publications (Bacon *et al.* 2006, Cole *et al.* 1997, Leung *et al.* 2002, Leung & Louie 2008, Manning *et al.* 2006, Marion *et al.* 2006, Marion & Hockett 2008b). Advantages of census surveys include the ability to produce maps showing the location and spatial arrangements of informal trail networks, document the number of trail segments and aggregate lineal extent, perform GIS analyses to investigate proximity to rare flora or fauna or sensitive environments, evaluate landscape fragmentation, and perform other relational analyses.

Resource conditions along informal trails can also be assessed to document effects on vegetation and substrates. A common method is to assign a condition class rating, generally five categories describing increasing levels of trampling impact from a faint trace to a barren and eroded tread (see examples in Manning *et al.* 2006 and Marion *et al.* 2006). Informal trails are broken into separate segments whenever condition classes change categories. Other tread condition indicators such as width and depth, and inventory indicators such as trail grade and vegetation type, can also be assessed using ratings and input as attributes of these segments (Rochefort & Swinney 2000). Resource condition assessments recorded for trail segments generally employ "typical" or categorical range data representative of the entire segment, resulting in some inaccuracies because these assessments are generally not measured. Measurements that are more accurate can be taken using a point sampling approach, generally employing a fixed interval between points with a random start. This method was employed by Wood and others (2006) to characterize informal tread width, depth, cross sectional area soil loss, and estimated total area of disturbance.

STUDY AREA

The study area for this research was the Mount Desert Island (MDI) portion of Acadia National Park, located on the Atlantic coast of Maine, USA (Figure 4). This 68,940 acre glaciated rocky island includes 32,864 acres in park ownership (47.5 % of the island). Park visitation was approximately 2.2 million visitors in 2009 (NPS 2009) with the busiest tourist season during summer (late June-August). Extensive networks of graveled carriage roads (non-motorized, multiple-use) and natural-surfaced formal hiking trails provide visitors with recreation opportunities throughout the park (Figure 4). The formal trail survey was restricted to assessing the 120 miles of formal hiking trails for the purpose of establishing and monitoring standards of environmental quality (excluding the carriage road system).

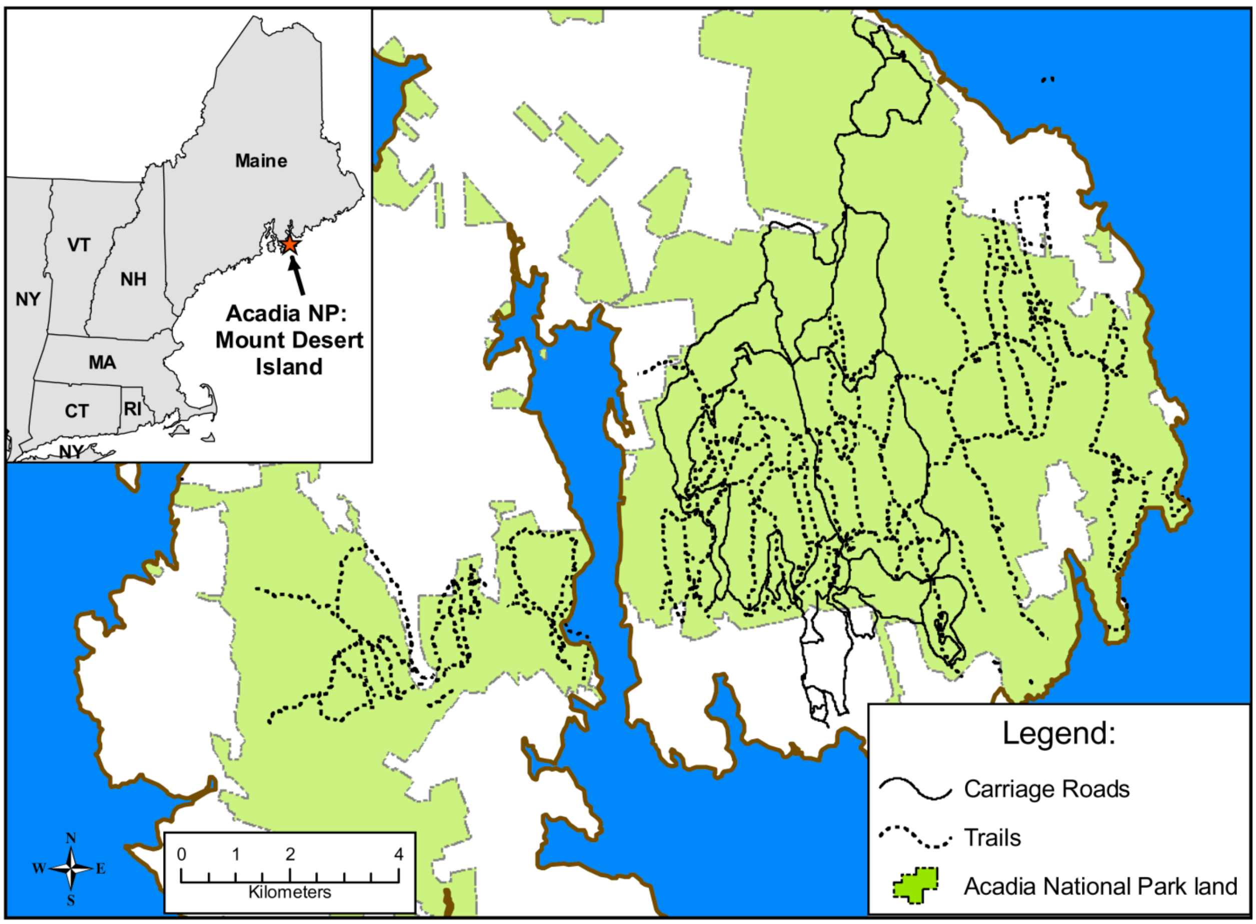


Figure 4. Acadia National Park, Mount Desert Island trails and carriage roads. The island has over 183 km of hiking trails within the park boundaries.

The terrain on MDI is highly varied. Beaches and cliffs along the rocky coastline give way to steep bedrock-strewn ridges interlaced with woodlands, numerous clear lakes, and a glacial fjord. Pleistocene glaciations shaped much of the island, resulting in the current landscape dominated by long gently sloped north-south ridges with extremely steep east-west faces. Trails were crafted during the late nineteenth and early twentieth centuries. Historically there were more than twice as many trails on MDI as there are presently (NPS 2002).

Some MDI trails are unique because of the exceptional amount of stone crafting used in their construction. For historic preservation purposes, the steep direct-ascent alignments of the oldest trails are preserved by the NPS as historic park features. A few of the steepest trails resemble via ferrata-style hikes, featuring rockwork staircases or metal handholds, ladders, and rails. The smooth granite domes of Acadia National Park have long attracted visitors because of their outstanding views and relatively easy accessibility for the average hiker. Cadillac Mountain, the highest point on the east coast, was reached by carriage and cog railroad as early as the 1880s; it now receives an estimated 500,000 visitors annually, most arriving via the auto road built in the 1930s. Many other summits are destinations for hundreds of hikers every summer day.

Severe growing conditions (cold, ice, wind) and thin soils have created a fragile sub-alpine environment at higher elevations throughout the park that is neither resistant nor resilient to human use. Several globally to locally rare plant species are found throughout Acadia's granite balds. Ecologist and author Tom Wessels has described the lichens of Acadia as more diverse and luxuriant than any other granite area in the U.S., and notes that the extensive mats of lichens and mosses are cryptogamic, and as fragile as their western counterparts (Wessels 2001).

The lack of "resistance" in this landscape (natural physical barriers such as uneven bedrock, jumbles of large loose rocks, or dense vegetation) encourages intentional as well as inadvertent wandering and exploration. Visitors wander off formal trails to seek a different view, a view-shed with fewer people in it, a photo opportunity, exploration, or to pick blueberries. Even when hiking trails across open granite are seemingly well marked, hikers stray from the desired path because it's easy to do so and they can't easily get lost.

The loss of soil and vegetation from high use and the "wandering and exploration" behaviors are a principal concern for park managers. An action item listed in the park GMP (NPS 1992) to mitigate impacts from human use highlights Cadillac Mountain and other summits. Since 1997, ridge-runners sponsored by Friends of Acadia have roamed all the summits educating visitors about Leave No Trace principles, especially the need to stay on the trail and use durable surfaces, while also monitoring visitor use numbers. The entire Acadia trail system is now undergoing substantial rehabilitation, thanks to a partnership with Friends of Acadia and strong fund-raising by the park and its partners. The results of this research will help inform rehabilitation work and prevent the renewed deterioration of trail corridors because of uninformed visitor behavior. These activities are indicative of the park's increasing commitment to protecting these resources.

METHODS

Given park objectives and their implementation of a VERP planning and decision-making framework, we emphasized measurement-based procedures in our selection and development of formal and informal trail monitoring procedures. To maximize flexibility in the future selection of appropriate trail condition indicators and comparisons to the baseline conditions documented by this study we developed and applied procedures for an array of potential indicators.

Impact assessment procedures were developed and applied to all unpaved formal trails and to a selection of informal trails in two areas of Acadia NP. Jeremy Wimpey and Logan Park conducted fieldwork for this report in July and August, 2007, with substantial logistical and field assistance provided by Charlie Jacobi. The following sections describe the sampling design, field methods, and analysis procedures applied to collect and analyze the impact assessment data.

Trail Assessment Procedures

Formal Trails

Research goals were to develop and apply accurate and precise trail condition monitoring protocols and provide baseline data for use in selecting environmental indicators and standards of quality. As concluded by Marion and Leung (2001), point sampling methods provide more useful and appropriate data for these purposes than problem assessment methods. Based on the findings of Leung and Marion (1999b), the substantial length of the MDI trail network, and the need for an efficient method that NPS staff can replicate as part of a long-term monitoring program, a 500 ft point-sampling interval was selected. This interval provided 1,117 sample points, permitting robust statistical analyses and the ability to characterize trail conditions across the entire trail network.

Traditionally, point-sampling trail surveys involve pushing a measuring-wheel along the trail and stopping at a fixed distance interval following a random start. Measuring-wheels introduce an unknown amount of measurement error that varies with terrain. The rugged MDI terrain, including stone staircases and vertical ascents, presented additional problems for measuring-wheel use. These problems were resolved using ESRI's ArcMap 9.3 software and a macro subprogram called "PointsalongPoly" (Hitchen 2007) to locate the sample points along the trail network at the specified 500 ft (152.4 m) interval (Figure 5). The function of the macro was to place points along a line feature at the specified sampling interval. The GIS trail layer was "dissolved" prior to applying the macro to aggregate the individual trail segments, ensuring points were placed at the appropriate interval across the network. Inspection and minimal editing of the sample points were required to omit or relocate points placed at trail junctions or in close proximity to other points. A small number of sample points were added to trail segments that received one or no sample points. Onscreen measurement of the distance between points aided the adjustment of point positions. The resulting point sampling layer was loaded onto a Trimble® GeoXT handheld GPS device (Figure 6). Field staff navigated to each sample point using the GPS device, fitted with a backpack ground plane antenna and an extended use battery. Bias in locating sample point locations was avoided by placing the transect stakes at the field staff's leading foot at the first occurrence of a proximity alarm for the GPS sample point. A data dictionary created in Trimble's Pathfinder Office software and uploaded to the GPS enabled paperless recording of trail condition data. Data were downloaded daily to computers. Use of trade, product, or firm names does not imply endorsement by the U.S. Government.

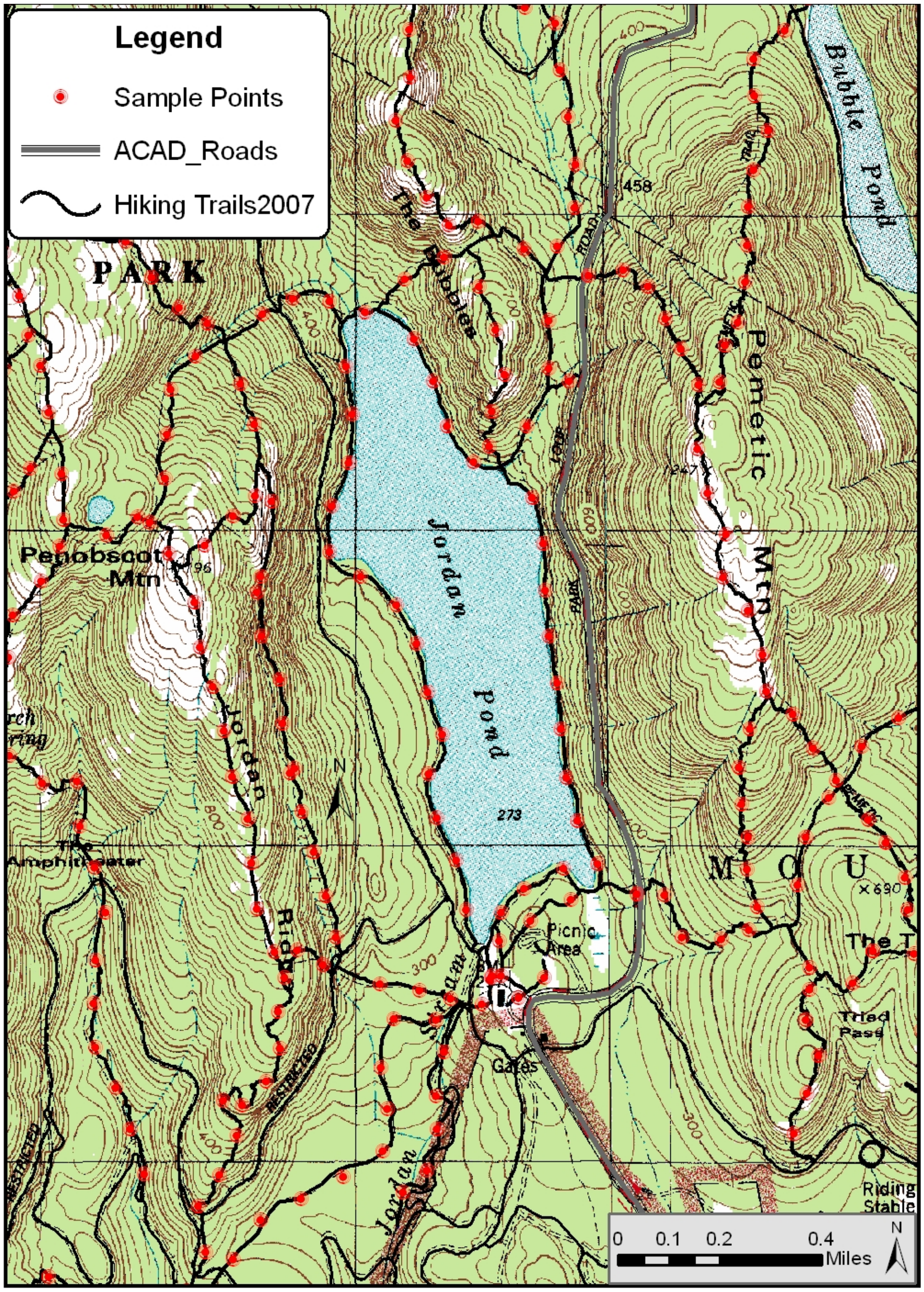


Figure 5. Enlarged portion of study area showing trails with sample point locations. Note the fall-line orientations (trail alignments perpendicular to contour lines) of some trails up steep mountain slopes.

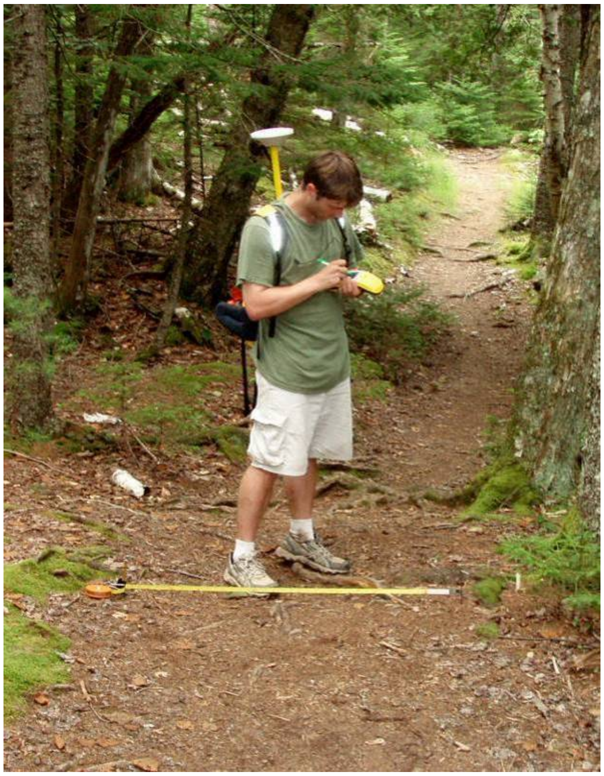


Figure 6. Trail assessment and paperless data recording using a GPS unit at a transect established on a sample point.

A detailed description of the condition assessment procedures applied to formal trails is presented in Appendix 1 and summarized here. At each sample point, a transect was established perpendicular to the trail tread with endpoints defined by the most visually obvious outer boundary of trampling-related disturbance. These boundaries are defined by pronounced changes in ground vegetation height (trampled vs. untrampled), cover, composition, or when vegetation cover is reduced or absent, by disturbance to organic litter or lichen (intact vs. pulverized). Trail boundary definitions were illustrated with photographs and a consistent objective was to define the trail tread that receives the majority (>95%) of traffic (see Appendix 1, Figure 1). The distance between these disturbance-associated boundaries was measured as trail width (Table 4). Trail width was coded as “not applicable” in instances when sample points fell on barren non-vegetated bedrock (ledge).

At each transect, survey staff assessed the grade of the trail and the dominant fall-line (landform grade). Trail slope alignment angle (TSA) was assessed as the difference in compass bearing between the prevailing landform slope (aspect) and the trail’s alignment at the sample point (Leung & Marion 1996)(Table 4). The TSA of a contour-aligned trail would equal 90^o while a true “fall-line” trail (aligned congruent to the landform slope) would have a TSA of 0^o. The landform position of the trail relative to the local topography was determined as side-hill or fall-line. Tread surface composition was assessed in the following categories: bare soil, vegetation, organic litter, roots, natural rock, stonework, and man-made materials (wood or gravel). For each category, the percent of trail width was recorded to the nearest 5%. A count of additional secondary trails that paralleled the survey trail at each sample point provided a measure of the extent of trail braiding.

Table 4. Description of trail impact and inventory indicators and calculation methods.

Impact Indicators	
Trail Length	Total length of the trail segment being assessed, summed to obtain an aggregate measure for each study area.
Trail Width	Width of trail that captures about 95% of all traffic, including trail-sides up to the pre-use land surface for fall-aligned trails or up to the estimated post-construction tread surface for side-hill trails. Assessed at sample points along each trail and averaged for each trail to obtain mean trail width.
Trail Width Difference	Difference between assessed and intended trail width; positive values indicate a wider than intended trail, negative values indicate a narrower than intended trail.
Area of Disturbance	The mean trail width times the trail length.
Maximum Incision	Maximum trail depth measure at each sample point transect from the tread surface to the estimated pre-use or post-construction land surface.
CSA Soil Loss	An estimate of soil loss at each sample point from erosion, soil displacement, or compaction, assessed through vertical measurements at a fixed interval across the trail width from the pre-use or post-construction land surface to the current tread surface. Mean CSA is calculated as the average of CSA values measured at the sample points for each trail segment.
CSA Volume	The mean CSA for a trail times trail length – an estimate of the total volume of soil lost from a trail.
Mean Trail Depth	Calculated by dividing mean CSA by mean trail width.
Inventory Indicators	
Rugosity (roughness)	Rugosity was calculated as the standard deviation of the vertical CSA measurements at each transect
Trail Grade	Percent grade of the trail at the sample point. Measured with a clinometers.
Trail Slope Alignment Angle	Difference in compass bearing between the prevailing landform slope (aspect) and the trail's alignment at the sample point. Ranges from 90^o for a contour-aligned side-hill trail, to 0^o for a fall-aligned trail.
Trail Slope Ratio	The quotient of trail grade and landform grade. Trail design guidance recommends a slope ratio of < 0.5 to facilitate water removal from trails.

The cross sectional area (CSA) of soil loss (in^2), from a taut fiberglass tape measure to the tread surface, was measured using a fixed interval method (Cole 1983) (Figure 7, See Appendix 1 for detailed procedures, including Figure 2 at the end of this Appendix). This measure includes "soil loss" from water/wind erosion, soil compaction of the trail substrates, and soil displacement from traffic. Temporary stakes were placed at positions that enabled a tape measure to be stretched along what survey staff judged to represent the original land surface for fall-line trails, or the post-construction tread surface for constructed side-hill trails. Vertical measurements from the tape measure to the trail substrate surface were taken at a fixed interval of 0.3 ft for the majority of trails, with 1 ft intervals for the trails wider than about 8 ft (rare).

CSA provides a more accurate measure of trail soil loss that can be extrapolated to provide an estimate of total soil loss from each trail (ft^3). CSA was calculated from the data collected at each sample point using spreadsheet formulas. CSA measurements were not able to be assessed when sample points fell on man-made materials (boardwalks, elevated treads, stonework) or on bare bedrock. As a consequence, CSA measures were completed for 492 of the 1117 transects in the sample population. This proportion is indicative of the uniquely rocky/crafted environment of the ACAD trail system.

Trail condition measures were calculated for each trail and for all trails combined, including area of disturbance, CSA, and mean trail width and depth (Table 4). For example, "area of disturbance," an estimate of the land area intensively disturbed by trail traffic, was calculated by multiplying trail length by mean trail width. CSA volume, an estimate of aggregate soil loss (CSA ft^3), was calculated by multiplying mean CSA (converted to ft^2) by trail length.

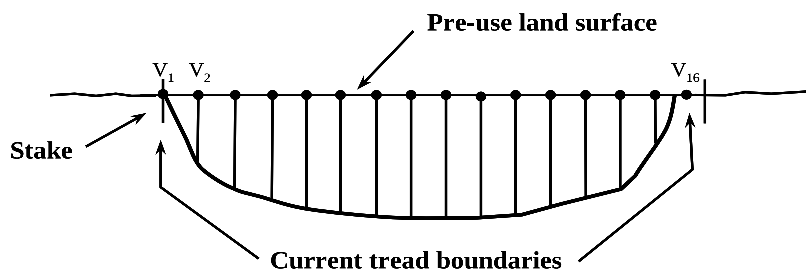


Figure 7. Illustration of the fixed interval CSA method for assessing soil loss at each transect.

The rugosity, or roughness, of the trail surface was calculated from measurements taken to compute CSA estimates. Rugosity was calculated as the standard deviation of the vertical measurements at each transect. This value is a linear analog of the rugosity values that Bayfield (1973) calculated from quadrat frame data. Rugosity was not assessed for transects located on man-made materials (boardwalks, elevated treads, stonework) or bare bedrock, reducing the number of usable sample points from 1117 to 492 (44%) when this variable was used in analyses. This proportion indicates the uniquely rocky or crafted environment of the ACAD trail system.

High-resolution digital photographs and averaged GPS locations, differentially corrected to increase point accuracy, were recorded at each transect to guide field staff in replicating procedures along the same transects during future monitoring cycles. Transect photographs were utilized to create two additional attributes for each trail transect: trail substrate class (natural, graveled, stonework, bridge/boardwalk) and trail borders (none, one, or two), defined as human-placed logs or rocks lining the trail edges.

Using trail counter and trailhead/trail intersection use counts and personal experience, knowledgeable NPS and trail maintenance staff assigned use levels (high, medium, and low) to each MDI trail segment. Trail management and maintenance staff provided data for all trail segments specifying intended trail width for each trail segment. These data were spatially joined to transect data using ArcMAP 9.3 by assigning use level and intended width from the trail segment containing each sample point. Random and purposively selected sample points were checked and verified to ensure the accuracy of the spatial join procedure.

Data were assembled in the attribute table of the transect data shapefile in ArcMap 9.3, and then exported to Microsoft Excel 2003 and SPSS 16.0 for analyses. The difference between assessed and intended trail width was calculated as trail width difference; positive values indicate a wider than intended trail, negative values indicate a narrower than intended trail. The quotient of trail grade and landform grade was calculated as slope ratio. Trail design guidance recommends a slope ratio of less than 0.5 to facilitate water removal from trail treads (IMBA 2004).

A series of statistical tests was performed in SPSS to investigate relationships between dependent and independent variables. Analyses focused primarily on understanding the dependent variables of interest: trail width/width difference, and CSA soil loss. Regression analyses used general linear models and backward step-wise selection methods to isolate variables that significantly influence the dependent variables. Categorical variables were represented with dummy variable coding to evaluate the relative influence of each category. Overall models were developed, along with models that grouped variables into use-related, environmental, and managerial categories. ANOVA tests compared the values of trail width/ width differences and CSA soil loss against influential independent variables.

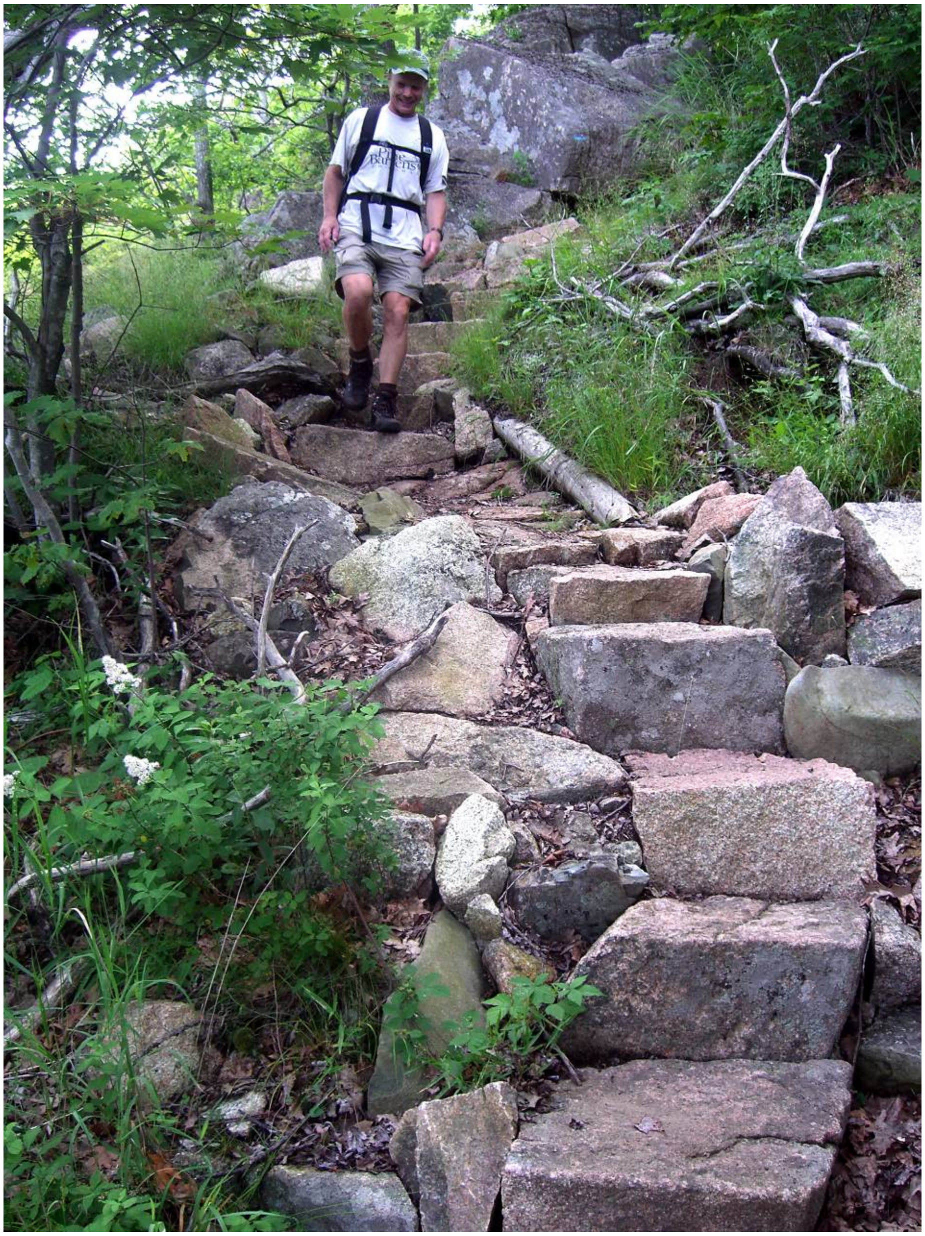
Informal Trails

Informal trails were mapped as lineal features using a Trimble GeoXT GPS with external Hurricane antenna. These data were collected as part of a census survey of the trails within two park areas: Lakewood and Bass Harbor. All GPS data were post-processed using Trimble's Pathfinder Office 4.0 and base station data from the nearest available Continuously Operating Reference Station (CORS). Informal trail conditions were assessed during field collection using a condition class (CC) system, as previously implemented in rapid assessment surveys of formal trails (Marion et al. 2006, Wimpey & Marion 2011). Condition class ranged from 1-5 with an increase in value associated with greater departures from natural conditions, with regard to the condition or change in relative cover of vegetation, organic material, and mineral soil (Table 5). A new informal trail segment was designated and assessed when a change in condition class was noted in the field. Changes in condition class that were highly localized (< 10m) were not mapped. Point data were collected at formal and informal trail junctions and at endpoints to aid in the GIS editing process.

Post-processed GPS data were converted to ESRI ArcMAP 9.3 shapefiles for editing and analysis. Aerial imagery of the park was utilized during editing to improve editing accuracy and provide spatial context. Due to the nature of GPS data, the shapefiles required positional editing to create an accurate representation of the trail networks. The majority of this work involved snapping informal trail segment endpoints to the formal trail network and to other informal trail end points at junction points. Junction point data greatly improved the accuracy and efficiency of editing processes by providing anchor points for snapping trail segment endpoints.

Table 5. Condition Class rating descriptions applied to informal trails.

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.



RESULTS

Formal Trails

The formal trail survey assessed conditions at 1117 sample points selected to be representative of the 114-mile MDI trail system. While trail condition assessment surveys are focused on achieving long-term monitoring objectives, they also provide an opportunity to collect useful data characterizing the current physical attributes of the trail system. Such data can be used to evaluate the sustainability of the trails and to understand the relative influence of various factors on trail condition. Two such inventory indicators assessed in this survey are trail grade and trail slope alignment angle. It is common knowledge among trail managers and reported in numerous studies that soil loss on trails is strongly influenced by trail grade. The speed of surface water runoff intercepted and carried downhill along trail treads increases exponentially with increasing trail grade (Dissmeyer & Foster 1984). In contrast, trails located in flatter terrain exacerbate the two other core trail impact problems, tread muddiness and excessive widening.

The distribution of trail grade values for MDI trails illustrates their susceptibility for all three core trail impact problems. Approximately 18% of the trail system is located in flatter terrain (0-2% grade) where treads can be susceptible to widening and muddiness problems (Table 6). Fortunately, substantial amounts of granitic rock and granules in most soils prevent muddiness from being particularly troublesome, and managers have effectively used boardwalk and occasionally gravel in most locations with wet organic soils. Such actions also effectively address trail widening, along with dense woody vegetation common to lowland settings. Of greater concern are data revealing that 31% of the trail system has grades exceeding 15% (Table 6). Trail manuals generally recommend keeping trail grades below 10% (Hooper 1988) or 12% (Hesselbarth & Vachowski, 2000) to limit soil erosion, with rockwork often needed to harden and reduce erosion on treads greater than 15%. However, the mean grade of MDI trails is 13.2% and 10% of the MDI system has trail grades exceeding 30%. Many of these excessively steep alignments have constructed rock steps or ascend exposed rock faces with anchored metal rungs, which are not susceptible to soil loss. Analyses presented later in this section investigate the relationship between trail grade and tread soil loss.

A trail's slope alignment angle, as described in the methods section, is the angle between the prevailing landform slope (aspect) and the trail's alignment extending downhill from the sample point. In contrast to trail grade, the influence and importance of this indicator is not widely known or investigated, though recent studies suggest it may be as influential as trail grade (Aust *et al.* 2005, Marion & Olive 2006). Incredibly, half (50%) of MDI trails are aligned within 22^{o} of the landform aspect or fall line (Table 6), the path naturally taken by water running down a mountain slope. Figure 8 depicts a fall-line trail with substantial erosion, in comparison to the side-hill trail in Figure 6 that has a slope alignment in the $69\text{-}90^{o}$ range. While 22% of these fall line alignments are located on grades of less than 11%, 21.3% are located on grades of more than 15% (Table 6).

Table 6. Cross tabulation of trail grade and trail slope alignment inventory indicators.

Inventory Indicators		**Trail Slope Alignment Angle**				
		0-22°	23-45°	46-68°	69-90°	Totals
Trail Grade	0-2%	60[1]	10	25	102	197, 17.6%
	3-6%	95	20	53	80	248, 22.2%
	7-10%	95	30	20	42	187, 16.7%
	11-15%	68	24	26	24	142, 12.7%
	16-20%	71	13	11	7	102, 9.1%
	21-30%	85	24	14	6	129, 11.5%
	31-100%	82	8	14	8	112, 10.0%
	Totals	556 49.8%	129 11.5%	163 14.6%	269 24.1%	1117, 100%
Trail Grade:		Mean = 13.2%		Median = 9%		Range = 0-100%
Trail Slope Alignment:		Mean = 32.4°		Median = 24°		Range = 0-90°

1 – Number of sample points. Divide by 1117 to determine percentage of MDI trail system.

Figure 8. Notice the greater soil loss associated with this fall-line trail alignment compared to the more minimal soil loss for the side-hill aligned trail in Figure 6.

Once a fall-aligned trail becomes incised, water trapped on the tread is exceptionally difficult to direct off and can build in volume, substantially increasing its erosivity (Figure 8). As previously noted, erosivity also increases exponentially with trail grade, though the natural rockiness of Acadia's trail treads and frequent stonework can limit erosion. In flatter terrain, such trail alignments are susceptible to muddiness and widening. Rerouting fall-aligned sections is generally preferred, though alternative routes may not be possible due to cliff-lines or land ownership. In addition, park staff feel compelled to retain most of these alignments on the basis of their historic values, including the protection of historic stonework along many trails. However, fall-aligned trails with grades exceeding 15-20% frequently require significant investments in rockwork and ongoing maintenance to keep them sustainable. Water can drain under or over such work, though freezing winter temperatures can increase danger to trail users or harm and loosen the rockwork.

Trail Condition Indicators

Trail width ranged from 0 to 198 inches with a mean of 37.7 (Table 7). One-quarter of the trails exceed four feet in width. Mean trail width difference was 5.6 inches (Table 7), indicating that trails are generally 21% wider than intended by park management. The total area of intensive trampling disturbance associated with the MDI trail system is estimated to be 43.6 acres, based on calculations extrapolating mean trail width to the 120-mile MDI trail system. This amounts to 0.0013% of the park acreage on MDI. See Wimpey and Marion (2010) for a journal paper that presents more comprehensive data and analyses focused on this study's trail width findings.

Assessed soil loss on trails is attributable to several causal factors, including erosion from water or wind, compaction from traffic, and soil displacement to the trailsides or downslope. Recognizing these differing causes, we refer to all as "soil loss" henceforth. At the locations where it was possible to apply this procedure (N=490), maximum incision ranged from 0 to 9 inches with a mean of 2.6 (Table 7). However, 627 sample points were located on bedrock, crafted stonework, or wooden boardwalk where such measures were inappropriate. Assuming no soil loss at these locations (i.e., incision = 0) yields a more valid trail system mean maximum incision measure of 1.4 inches.

Cross-sectional area soil loss measurements, while more time-consuming, provide a more accurate estimate of soil loss. CSA ranged from 0 to 744 in^2, with a mean of 84.8 in^2 (Table 7). As with incision, staff were unable to assess CSA at many locations (N=628) and assuming no soil loss at these locations yields 36.7 in^2 as a more valid estimate of mean soil loss for the entire MDI system. A calculation extrapolating this measure by the trail system length yields an estimated aggregate soil loss of 153,405 ft^3 (5,681 yd^3 or 568 ten cubic yard dump trucks). On a per-mile basis, soil loss is approximately 1,346 ft^3/mile (49.8 yd^3/mile).

A more representative measure of trail incision is provided by calculating mean trail depth from the vertical measures recorded to compute CSA. This measure ranged from 0 to 12.6 inches with a mean of 2.1 inches (Table 7). Substituting 0's for locations where incision and CSA could not be assessed provides a more valid mean measure of 0.9 inches. Finally, field staff assessments of the tread substrate as a proportion of transect width are used to characterize the typical trail system substrates depicted in Figure 9. The predominant tread substrate is rock (34.4%), followed by organic surface litter (26.6%) and soil (14.7%). The manmade category (12.9%)

Table 7. Number and percent of sample points by impact indicator category.

Indicator	Sample Points	Percent[1]
Trail Width (in)		
0-24	282	25.2
25-36	319	28.6
37-48	238	21.3
49-60	151	13.5
60+	116	10.4
Missing	11	1.0
Mean = 37.7 Median = 36 Range = 1-198		
Trail Width Difference (in)		
-59- -30	32	2.9
-29- -6	295	26.4
-6- +6	315	28.2
6-30	342	30.6
30-60	101	9.0
60+	21	2.0
Missing	11	0.9
Mean=5.6 Median=4.0 Range= -59-174		
Maximum Incision (in)		
0	8	0.7
0.1-0.5	10	0.9
0.51-1.0	34	3.0
1.01-3.0	262	23.5
3.01-5.0	119	10.7
5.01+	57	5.1
Missing	627	56.1
Mean = 2.6 Median = 2.0 Range = 0-9		
Mean w/missing coded as 0 = 1.4 Median = 0		
Cross Sectional Area Soil Loss (in^2)		
0	8	0.7
1-100	348	31.2
101-200	93	8.3
201-400	34	3.1
401+	6	0.5
Missing	628	56.2
Mean = 84.8 Median = 60.0 Range = 0-744		
Mean w/missing coded as 0 = 36.7 Median = 0		
Mean Trail Depth (in)		
0	8	0.7
0.1-0.5	23	2.1
0.51-1.0	76	6.8
1.01-3.0	298	26.7
3.01-5.0	55	4.9
5.01+	27	2.4
Missing	630	56.4
Mean = 2.1 Median = 1.7 Range = 0-12.6		
Mean w/missing coded as 0 = 0.9 Median = 0		

1 – Percent of all sample points (including missing), i.e., percent of the MDI trail system.

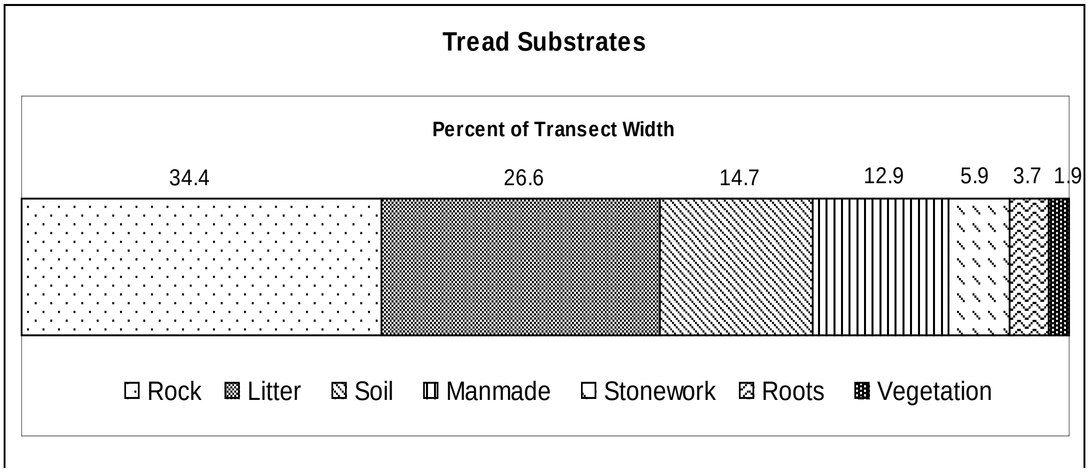


Figure 9. Mean trail substrate cover as a proportion of transect (tread) width.

includes wood surfacing associated with boardwalks and human-placed gravel. Highly crafted stonework tread surfacing contributes 5.9%, followed by roots (3.7%) and vegetation (1.9%). Field staff did not assess mud or standing water, as these were rarely encountered. One exception is the flat, wide Jesup Path, which had an extended muddy section containing three sample points.

Inventory and impact indicator data are also presented in Table 8 for a large number of trail groupings, specified by park staff to provide more meaningful summaries allowing direct comparison between smaller subsets of trails. This table includes summarized data on core trail design (e.g., grade, alignment angle), construction/maintenance (rugosity), and use (amount) so that these may be examined in relation to trail impact indicators. Park managers are in the best position to interpret these findings and their managerial significance. Note that mean values for some trail groups are based on a relatively low number of sample points; in particular, we advise caution when evaluating mean values based on fewer than 6-8 sample points.

As an aid, we also present in **bold print** the mean values for trail impact indicators representing the “worst” 5% of values, and have *italicized* values representing the “best” 5% of values (Table 8).

Table 8. Inventory and impact indicator data summarized by trail group.

Trail Group	Sample Count (CSA Count)[1]	**Inventory Indicators** Trail Grade (%)	Landform Grade (%)	Slope Ratio (%)	Slope Alignment Angle (°)	Rugosity (in)	Use Levels	**Impact Indicators[2]** Trail Width (in)	Width Difference (in)	Cross Sectional Area (in^2)	Maximum Incision (in)
	N	Mean	Mean	Mean	Mean	Mean		Mean	Mean	Mean	Mean
A Murray Young Path	12 (3)	17	27	0.74	24	0.72	L	31.6	-4.4	62	3
Acadia Mountain Trail	17 (3)	20	26	0.83	13	1.13	M	40.6	***-19.4***	111	3
Amphitheatre Trail	15 (10)	10	17	0.68	23	0.41	L	26.7	2.7	26	1.3
Asticou and Jordan Pond Path	18 (13)	6	11	0.68	34	0.51	L	40.2	-7.8	80	2.08
Bald Peak Trail	11 (7)	14	19	0.77	26	0.9	L	25.7	1.7	54	2.43
Beachcroft Path	12 (6)	12	33	0.45	58	0.84	L	28.8	4.8	44	2.17
Beech Cliff Loop Trail	5 (3)	9	39	0.45	57	1.33	M, L	47.8	11.8	**303**	1.67
Beech Mountain Loop Trail	10 (2)	14	26	0.66	36	0.91	M	47	-13	65	1.5
Beech South Ridge Trail	8 (4)	8	26	0.71	28	0.57	L	34.8	10.8	61	2
Beech West Ridge Trail	9 (5)	17	24	0.62	31	0.7	L	35.1	11.1	52	2
Beehive Trail	5 (2)	31	48	0.78	30	0.61	H	35.6	-0.4	86	3
Beehive/Bowl	1 (0)	42	58	0.72	29	N/A	H	51	15	N/A	N/A
Bernard Mountain Trail	20 (16)	14	19	0.85	16	0.95	L	34.3	-1.7	90	3.06
Bowl Trail	7 (5)	10	16	0.68	28	1.25	H	57.4	9.4	**219**	**5.2**
Bubble and Jordan Ponds Path	16 (8)	10	25	0.45	55	0.7	L	34.8	-1.2	46	1.88
Bubbles Divide Trail	2 (0)	31	38	0.64	30	N/A	M, L	37	***-23***	N/A	N/A
Bubbles Trail	17 (10)	19	24	0.92	7	0.56	M, L	29.1	-6.9	36	1.4

Trail Group	Sample Count (CSA Count)[1]	Inventory Indicators						Impact Indicators[2]			
		Trail Grade (%)	Landform Grade (%)	Slope Ratio (%)	Slope Alignment Angle (°)	Rugosity (in)	Use Levels	Trail Width (in)	Width Difference (in)	Cross Sectional Area (in^2)	Maximum Incision (in)
	N	Mean	Mean	Mean	Mean	Mean		Mean	Mean	Mean	Mean
Bubbles Trail, 41-5	6 (2)	25	32	0.85	14	0.59	H	52.5	16.5	64	1
Cadillac North Ridge Trail	22 (8)	10	29	0.56	41	1.42	M	38.4	14.4	**205**	3.75
Cadillac South Ridge Trail, 26-1,2,3,4	23 (6)	12	12	0.96	2	1.77	M	38.6	14.6	149	2.83
Cadillac South Ridge Trail, 26-5,6,7,8 and Eagle Crag	19 (14)	11	16	0.63	35	0.86	M	48.6	24.6	88	2.86
Cadillac West Face Trail	9 (0)	29	50	0.68	31	N/A	M	49.9	25.9	N/A	N/A
Cadillac-Dorr Connector	2 (0)	20	39	0.52	51	N/A	M	*18.5*	-5.5	N/A	N/A
Cadillac/Beech Cliffs	7 (1)	29	49	0.55	44	0.74	M	41.9	5.9	77	2
Canada Cliff Trail	8 (1)	22	25	0.93	16	0.45	L	50.6	**26.6**	33	1
Canon Brook Trail, 19- 1&5	14 (5)	23	30	0.8	21	1.01	L	24.3	-11.8	70	3.4
Canon Brook Trail, 19- 2,3,4	10 (8)	4	18	0.43	48	0.6	L	34.5	-1.5	61	2.14
Champlain North Ridge Trail	11 (7)	16	19	0.76	37	1.06	M	34.4	10.4	127	3.83
Champlain South Ridge Trail	15 (3)	13	21	0.74	24	0.82	L	39	15	66	2
Cold Brook/Gilley Trail	11 (9)	7	15	0.6	32	1.06	L	41.2	8.5	103	3.56
Day Mountain Trail	13 (10)	8	20	0.56	40	0.7	L	35.5	11.5	65	2.2
Deer Brook Trail	7 (2)	21	31	0.85	21	2.65	L	40.7	4.7	189	2.5
Dorr North Ridge Trail	7 (1)	24	29	0.87	16	1.84	L	35.1	11.1	196	**7**
Dorr South Ridge Trail	13 (3)	11	13	0.94	3	1.32	L	21	-3	108	1.67

Trail Group	Sample Count (CSA Count)[1]	Inventory Indicators						Impact Indicators[2]			
		Trail Grade (%)	Landform Grade (%)	Slope Ratio (%)	Slope Alignment Angle (°)	Rugosity (in)	Use Levels	Trail Width (in)	Width Difference (in)	Cross Sectional Area (in^2)	Maximum Incision (in)
	N	Mean	Mean	Mean	Mean	Mean		Mean	Mean	Mean	Mean
Eagle Lake Trail	18 (10)	3	29	0.23	68	0.7	L	31.4	7.4	60	2.8
Echo Lake Ledges Trail	1 (1)	12	25	0.48	54	1.87	H	**64**	16	204	5
Emery, Homans, Kurt Deidrichs, Ladder Trail	25 (5)	22	61	0.41	53	0.67	M, L	29.8	-2.8	44	2
Flying Mountain Trail	9 (2)	15	20	0.78	22	1.54	M	47.5	23.5	147	4
Giant Slide Trail	21 (13)	10	13	0.73	22	0.77	L	32.3	8.3	72	2.46
Goat Trail	6 (2)	31	33	0.92	13	2.23	L	61.7	**37.7**	194	**6**
Golf Course Trail	3 (3)	16	51	0.3	74	0.59	L	27.7	-8.3	27	1.33
Gorge Path	17 (5)	16	24	0.78	22	0.91	L	33.1	3.1	145	3.8
Gorham Mountain Trail	15 (6)	10	18	0.68	30	1.43	H, M	43.3	-4.7	107	4
Grandgent Trail	11 (6)	17	25	0.68	25	1.19	L	40.1	16.1	95	3.67
Great Head Trail	20 (13)	11	18	0.55	47	1.21	H	**77.2**	**34**	173	3.46
Great Meadow Loop	17 (0)	5	10	0.79	22	N/A	M	34.9	-13.1	N/A	N/A.
Great Notch Trail	20 (17)	11	16	0.71	20	0.74	L	34.3	-1.8	81	2.06
Hadlock Brook Trail	15 (8)	13	22	0.57	30	1.05	L	48.1	24.1	93	2.88
Hadlock Ponds Trail	14 (6)	7	17	0.56	46	1.15	L	40.2	16.2	103	3.17
Hemlock Path	4 (2)	8	14	0.8	20	1.24	L	51.3	**27.3**	147	3.5
Hunters Brook Trail, 35-1,2,3/Triad Pass	14 (9)	18	21	0.87	18	1.13	L	35.7	11.7	107	3.67

Trail Group	Sample Count (CSA Count)[1]	Inventory Indicators						Impact Indicators[2]			
		Trail Grade (%)	Landform Grade (%)	Slope Ratio (%)	Slope Alignment Angle (°)	Rugosity (in)	Use Levels	Trail Width (in)	Width Difference (in)	Cross Sectional Area (in^2)	Maximum Incision (in)
	N	Mean	Mean	Mean	Mean	Mean		Mean	Mean	Mean	Mean
Hunters Brook/Beach Trail 35-4	16 (15)	8	16	0.64	33	0.61	L	36.3	12.3	59	2.07
Jesup Path	10 (2)	3	8	0.86	11	0.35	L	42.9	-5.1	50	1
Jordan Cliffs Trail	14 (4)	19	58	0.55	44	1.24	L	48.3	24.3	196	3.67
Jordan Pond Carry	10 (8)	10	22	0.51	44	0.79	L	33.1	-2.9	52	2.25
Jordan Pond House & Nature Trail	8 (0)	3	4	0.83	14	N/A	H	**64.9**	16.9	N/A	N/A
Jordan Pond Path	31 (0)	3	34	0.13	77	N/A	L	37.4	-10.7	N/A	N/A
Jordan Stream Path	5 (3)	6	14	0.81	14	0.92	L	29.8	-6.2	73	3.25
Kane Path	8 (2)	5	21	0.36	54	0.15	L	29.3	-6.8	***5***	***0***
Kebo Mountain Trail	8 (4)	13	21	0.7	27	1.27	L	35.9	11.9	79	1.5
Ledge	2 (0)	26	45	0.71	15	N/A	L	34	10	N/A	N/A
Ledge Trail	5 (0)	26	32	0.75	28	N/A	L	43.1	19.1	N/A	N/A
Long Pond Trail	11 (10)	9	22	0.55	31	0.63	M	30.2	-17.8	75	2.9
Long Pond Trail (pondside)	20 (9)	5	62	0.12	70	0.7	M	42.7	-5.3	72	2.3
Lower Hadlock Trail	7 (6)	6	19	0.5	58	0.7	L	48	0	62	2.17
Mansell Mountain Trail	10 (5)	13	23	0.64	30	1.13	L	45.8	9.8	60	2.6
Maple Spring Trail	14 (1)	17	19	0.95	6	0.22	L	44.3	20.3	***5***	***0***
Norumbega Connector	9 (8)	10	19	0.69	34	0.76	L	34.3	10.3	83	2.25
Norumbega Mountain Trail	13 (7)	7	13	0.66	28	0.86	L	40.3	16.3	77	3
Ocean Path	21 (2)	7	21	0.47	46	0.53	H	57.4	9.4	33	1

Trail Group	Sample Count (CSA Count)[1]	Inventory Indicators						Impact Indicators[2]			
		Trail Grade (%)	Landform Grade (%)	Slope Ratio (%)	Slope Alignment Angle (°)	Rugosity (in)	Use Levels	Trail Width (in)	Width Difference (in)	Cross Sectional Area (in²)	Maximum Incision (in)
	N	Mean	Mean	Mean	Mean	Mean		Mean	Mean	Mean	Mean
Old Ocean Drive	4 (2)	7	14	0.7	41	0.35	L	59.3	11.3	22	1
Parkman Mountain Trail	19 (8)	13	23	0.67	31	1.22	M, L	33.2	9.2	85	3.5
Pemetic Mountain Trail, 31- 1,4-8	25 (16)	17	26	0.69	27	1.12	L	38.5	14.5	108	3.5
Pemetic Mountain Trail, 31- 2,3	6 (0)	20	24	0.94	9	N/A	L	***5.5***	***-18.5***	N/A	N/A
Pemetic Northwest Trail	6 (4)	32	37	0.91	19	0.9	L	39.7	3.7	44	2
Pemetic West Cliff Trail	7 (1)	23	25	0.94	6	1.24	L	21.9	-2.1	93	3
Penobscot East Trail	3 (1)	17	33	0.49	36	0.36	L	30.3	6.3	58	2
Penobscot Mountain Trail, 73-1,2,3	16 (9)	10	21	0.54	37	0.81	L	27.1	3.1	71	2.22
Penobscot Mountain Trail, 73-5	9 (3)	19	21	0.89	7	1.21	M	21.1	-2.9	96	3.33
Perpendicular Trail	9 (1)	37	65	0.65	41	1	M	33.9	9.9	30	2
Precipice Trail	6 (1)	31	73	0.48	64	3.76	H	35	11	**261**	1
Razorback Trail	10 (1)	20	31	0.82	19	0.38	L	29.9	5.9	60	3
Saint Sauveur Mountain Trail	17 (5)	8	13	0.6	34	0.4	L	32.2	20.2	29	1
Sargent East Cliffs Trail	6 (3)	33	39	0.72	28	3.04	L	***20.7***	-3.3	179	2.33
Sargent North Ridge Trail, 52-1,2,3	16 (7)	12	18	0.88	11	0.63	M	36.1	12.1	66	1.71
Sargent South Ridge Trail, 52-4,5,6	22 (10)	11	18	0.74	20	0.95	L	27.2	3.2	52	2.82
Schiff Path	10 (2)	18	40	0.57	52	1.32	L	25.4	-10.6	172	**6**

Trail Group	Sample Count (CSA Count)[1]	Inventory Indicators						Impact Indicators[2]			
		Trail Grade (%)	Landform Grade (%)	Slope Ratio (%)	Slope Alignment Angle (^{o})	Rugosity (in)	Use Levels	Trail Width (in)	Width Difference (in)	Cross Sectional Area (in^2)	Maximum Incision (in)
	N	Mean	Mean	Mean	Mean	Mean		Mean	Mean	Mean	Mean
Ship Harbor Trail	15 (0)	5	16	0.56	38	N/A	M	46.9	-1.1	N/A	N/A
Sluiceway Trail	9 (7)	11	24	0.71	20	0.54	L	35.5	11.5	61	2.14
Spring Trail	6 (3)	14	26	0.76	27	0.2	M	39.2	3.2	***13***	***0***
Stratheden Path	8 (8)	4	28	0.19	69	0.47	L	33.5	N/A	29	0.86
Tarn Trail	2 (2)	8	13	0.75	0	0.66	L	**63**	15	88	2
Valley Cove Trail	9 (4)	22	52	0.44	56	0.43	L	21.6	-2.4	***21***	***0.5***
Valley Peak Trail	14 (2)	23	30	0.74	27	0.69	L	31.9	7.9	43	2
Valley Trail	16 (14)	5	21	0.47	52	0.65	L	39.8	3.8	79	2.07
West Ledge Trail	9 (5)	18	21	0.84	25	0.74	L	32.1	8.1	64	2.8
Western Mountain Connector	4 (0)	2	7	0.61	28	N/A	L	52.5	***-43.5***	N/A	N/A
Trail System Mean	**11.5 (5.8)**	**14.74**	**26.53**	**0.66**	**32**	**0.96**	**N/A**	**37.7**	**5.6**	**84.8**	**2.6**
Standard Deviation	N/A	8.559	13.615	0.18	17	0.58	N/A	11.3	12.8	59	1.27

[1]Be aware of low “N” for some trail groups; a low point count or CSA point count (omitting bedrock transects) should be interpreted with caution as summary statistics are based on very few sample locations.

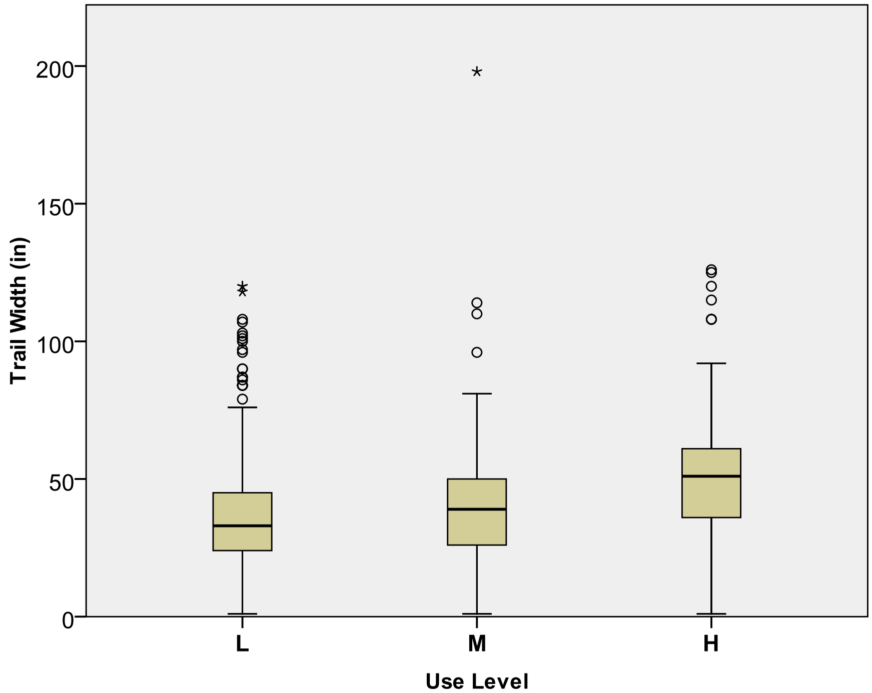
[2] Impact indicator values are **bolded** when the value falls in the “worst” 5% of values, and *italicized* when the value falls in the “best” 5% of values.

Trail Conditions by Use Level

The relationship between trail condition and level of trail use is presented in Figures 10 and 11. Trail width increases slightly with increasing use level, but trail width difference values are more uniform, with a slight increase for more heavily used trails (Figure 10). CSA soil loss and maximum incision values show somewhat stronger positive relationships with level of trail use (Figure 11). These figures characterize the distribution of values for these indicators by level of use and provide useful information if managers choose to set standards of quality for them as part of a carrying capacity framework. This section presents additional data characterizing the distribution of values for these potential indicators to facilitate management deliberations on selecting appropriate measures and values for standards of quality. Selecting standards is an inherently value-laden and subjective process. However, presentation of representative data characterizing the distribution of indicator values, when available, can greatly assist the process used to evaluate and select quantitative standards. The following presentation of data for these potential indicators provides different methods for characterizing the distribution of values.

Two methods for visually examining the distribution of values for these indicators are included in Figures 10 and 11 (Boxplots) and Figures 12-14 (Stacked Barcharts). Boxplots present the distribution's central tendency by a box whose lower and upper sides represents the 25th and 75th percentiles (or 1st and 4th quartiles), respectively. Thus, the box includes the middle 50% of the distribution of values for each indicator. The central line represents the 50th percentile or "median" value. The "whisker" lines extend above and below the box 1.5 times the interquartile range, the difference in the values of the 25th and 75th percentiles. Values beyond the ends of the whiskers are considered "outliers," with extreme outliers labeled with an asterisk.

The actual distribution of values for these indicators are presented in the stacked bar charts. The height of each bar segment represents the number of transects where that indicator value was measured (Figures 12-14) to assist in the selection of standards. These figures show the approximate number of trail transects that would exceed alternative values selected as standards for each level of trail use. For example, there is a natural break in the distribution for trail width difference, high use trails, at about 40 inches (Figure 12).



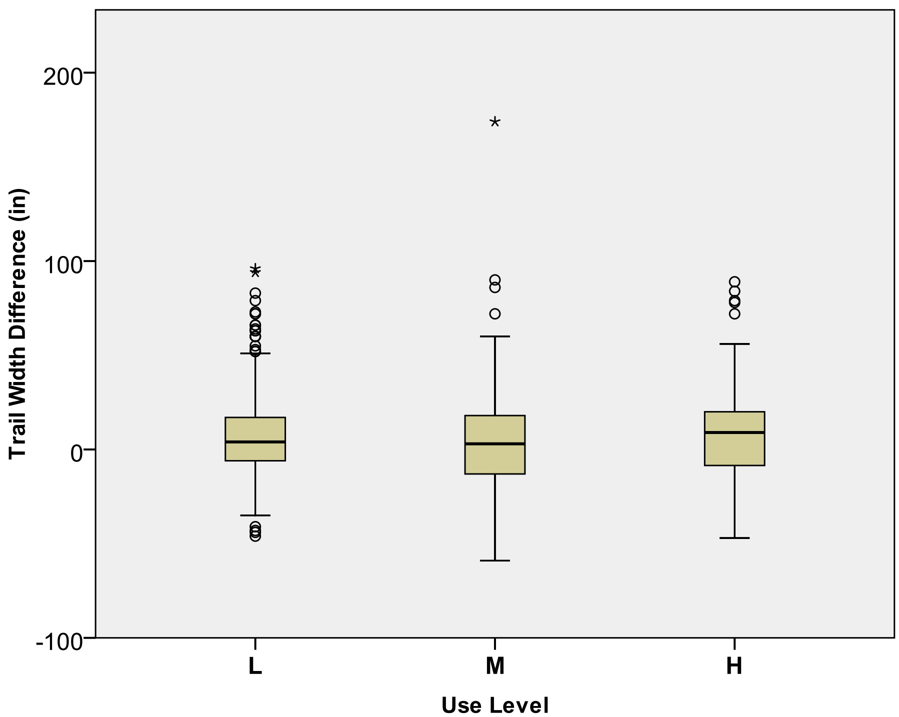


Figure 10. Box plots showing the distribution of trail width and trail width difference values for three levels of trail use.

Note: Boxes represent first (lower line) and third (upper line) group quartiles (the 25th and 75th percentiles); lines inside the boxes represent the overall mean for each group; vertical lines ("whiskers") represent the range of values; and outliers are "extreme values" that lay beyond the end of the upper whisker.

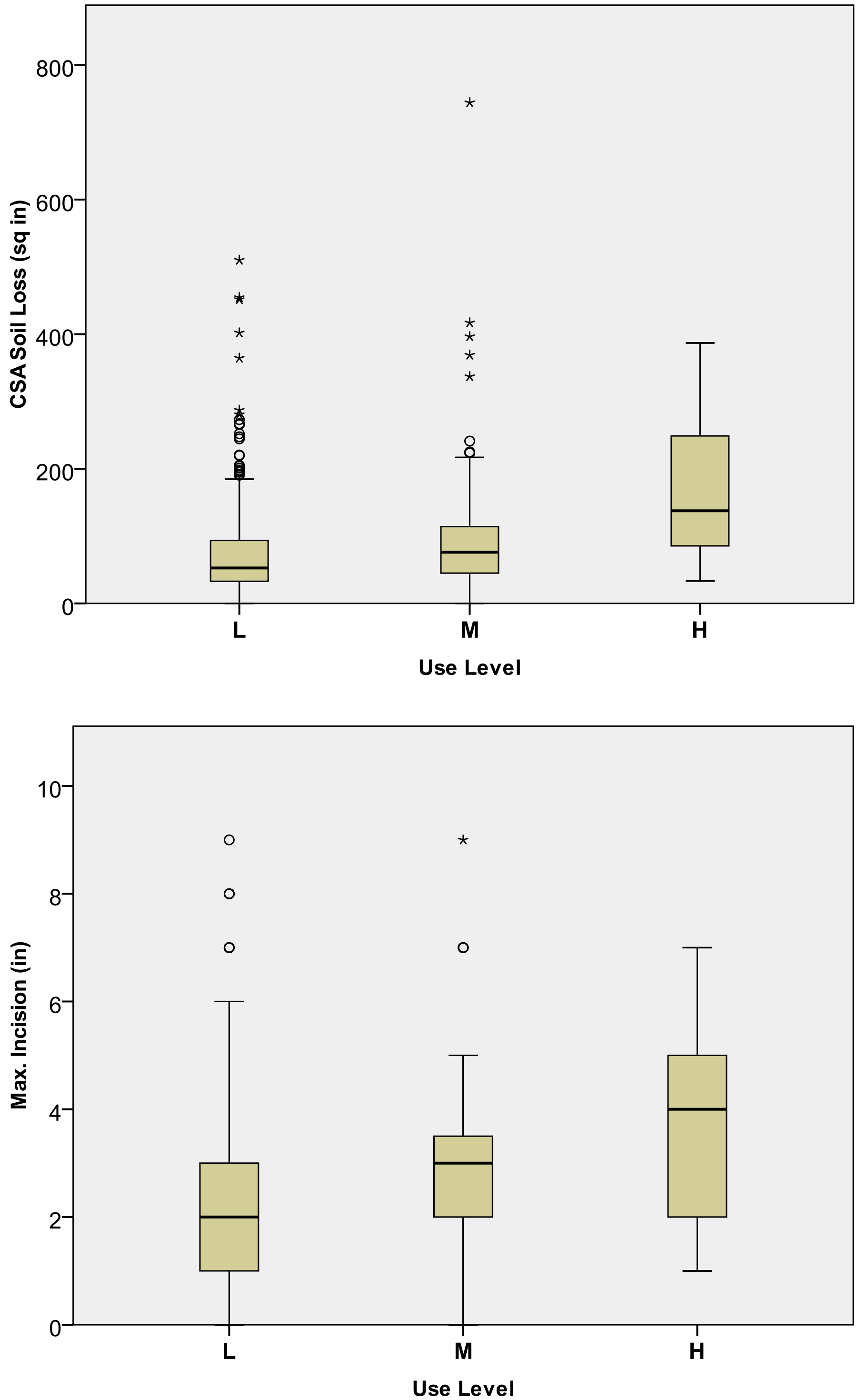


Figure 11. Box plots showing the distribution of CSA soil loss and maximum incision values for three levels of trail use.

Note: Boxes represent first (lower line) and third (upper line) group quartiles (the 25th and 75th percentiles); lines inside the boxes represent the overall mean for each group; vertical lines ("whiskers") represent the range of values; and outliers are "extreme values" that lay beyond the end of the upper whisker.

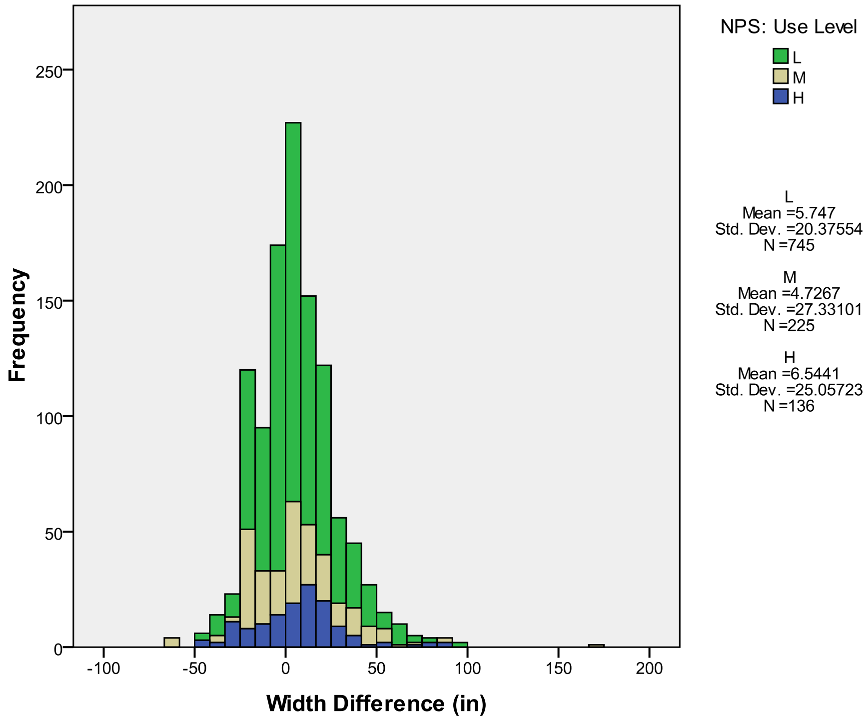


Figure 12. Stacked bar chart showing the relationship between frequency of width difference values and level of use.

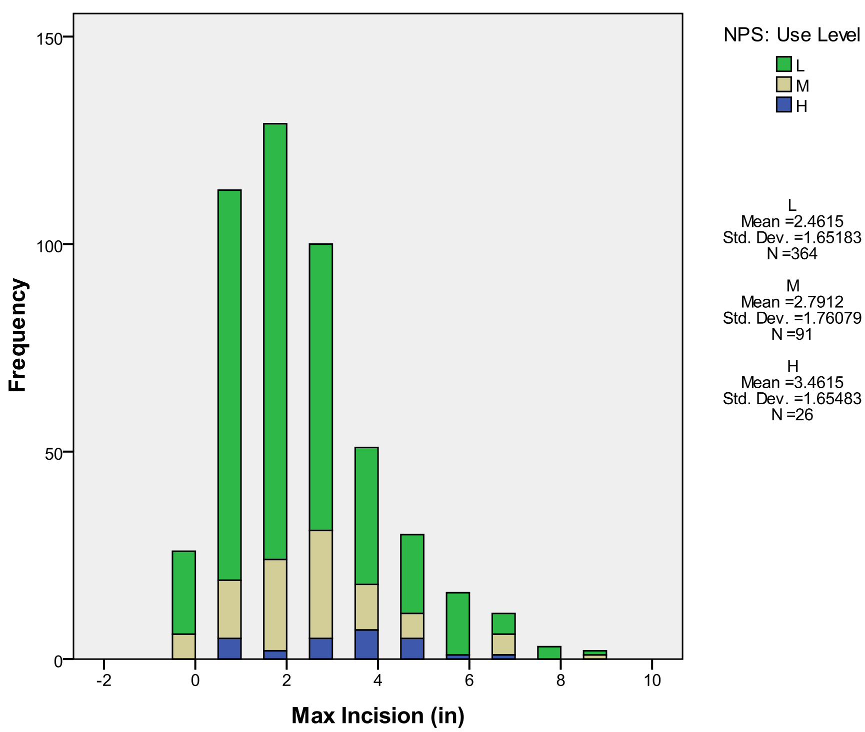


Figure 13. Stacked bar chart showing the relationship between frequency of maximum incision soil loss values and level of use.

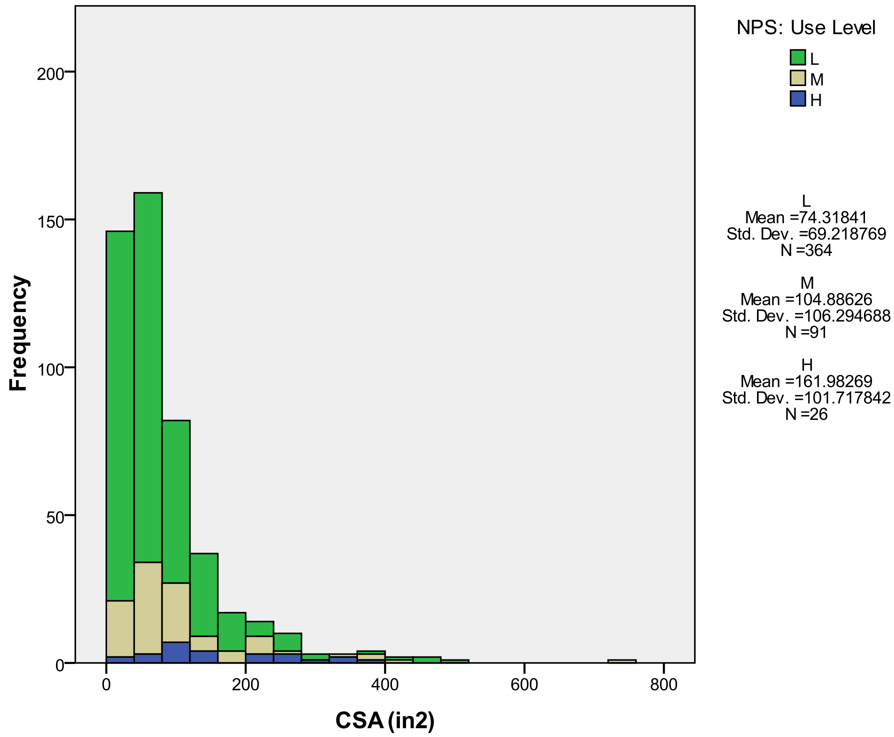


Figure 14. Stacked bar chart showing the relationship between frequency of cross sectional area loss of soil values and level of use.

Understanding Soil Loss

Trail degradation can be minimized through proper trail design (layout), by avoiding steeper trail grades and fall-line alignments. This section applies a relational analysis and statistical testing to evaluate the relative influence of these two factors on trail soil loss, as assessed with CSA measures. Our hypothesis is that trail alignments with steep grades and/or fall-line orientations are more susceptible to soil erosion and will have larger CSA values. The influence of both these factors was statistically tested with ANOVA (General Linear Model) and found to be highly significant (F/*p-value*: model = 4.1/.000; grade = 4.2/.015; slope alignment = 3.1/.047). Mean CSA values for three levels of trail grade and trail slope alignment angle are graphed in Figure 15. These findings are dramatic, illustrating the strong influence of both these core trail design factors. The least eroded trail segments are those aligned closest to the contour (slope alignment = 61-90) with grades of up to 12% (Figure 15). The influence of trail grade increases as trail slope alignment angles decrease from 90 (contour) to 0 (fall-line). In particular, substantial increases in CSA values are shown to occur for trail segments in the 0-30^{o} trail slope alignment category with grades in excess of 4%, and for trails with grades in excess of 12% (Figure 15).

We expect that soil loss could have been substantially higher if not for the substantial amount of exposed bedrock and rock commonly present in the soils of ANP. As previously noted, soil loss could not be assessed in 56% of the sample, often due to the presence of bedrock, and in locations where measurements were possible, rock comprised the largest percentage (34.4%) of the tread surface. A principal management implication of these findings is that park staff could

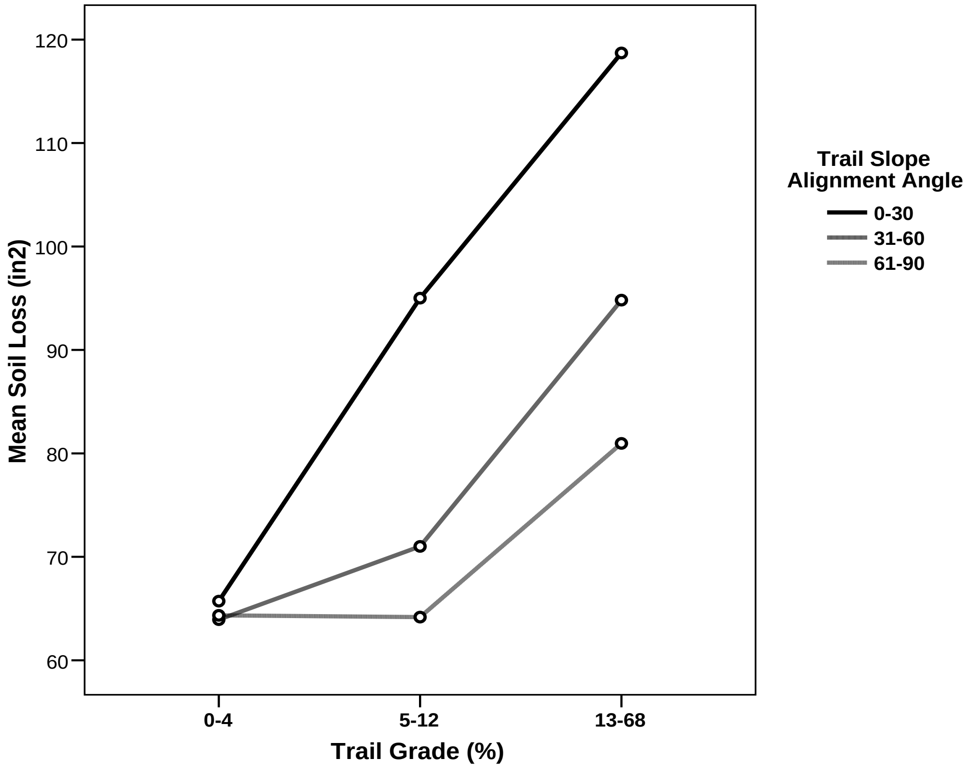


Figure 15. The influence of trail slope alignment angle and trail grade on soil loss, as measured by cross-sectional area.

effectively reduce soil loss in locations where soils are a predominant substrate component by relocating segments with steep grades and low slope alignment angles (e.g., grades >12% and alignment angles <30^{o}). Relocations to reduced grades would also likely create safer and more enjoyable hiking experiences. Improving tread drainage and installing rockwork in these locations would also be effective management responses, though such actions substantially increase initial construction and recurring maintenance expenses.

The subset of sample points with CSA measurements (n=472) were further investigated through a series of regression analyses to evaluate the individual and collective influence of use, environmental, and managerial factors on soil loss as assessed by CSA (Table 9) and maximum incision (MI) (Table 10). For CSA soil loss, a natural log transformation was required to normalize data; consequently, the regression coefficients are unstandardized natural log values. MI values did not require a transformation so regression coefficients in the respective tables are unstandardized values.

Four regression models were constructed for each dependent variable: 1) a use-related model that includes the categorical use level factor, 2) an environmental model with landform grade and landform position (side-hill or fall-aligned), 3) a managerial model with trail grade, TSA, slope ratio, and borders, and 4) an integrated model with all factors input and utilizing backwards step-wise selection to remove non-significant factors.

Table 9. Regression modeling to evaluate the influence of use-related, environmental, and managerial factors on soil loss (CSA).

Factors	Regression Models[1]			
	(1)	(2)	(3)	(4)
Use-Related				
Use Level:	(0.000)[2]			(0.000)
High	(0.002) 0.562[3]			(0.000) 63.705
Medium	0 (dummy code)			0
Low	(0.002) -0.304			(0.001) -25.944
Environmental				
Landform Grade		(0.007) 0.007		
Landform Position:		(0.000)		
Fall-line		(0.000) 0.424		
Side-hill		0 (dummy code)		
Managerial				
Trail Grade			(0.004) 1.239	(0.000) 1.423
TSA			(0.294) -0.194	
Slope Ratio			(0.868) 2.916	
Borders			(0.260) -11.538	
Adjusted R^2	0.062	0.049	0.038	0.123
Estimated Effect Size[4]	Small	Small	Small	Small-Medium

[1] Regressions run with General Linear Model using *ln*(CSA) as the dependent variable.
[2] Two-tailed t-test significance
[3] Unstandardized *ln*(CSA) coefficients, inches (e.g., high use trails are .562 in deeper, on average, than medium use trails, which are .304 in. deeper than low use trails. For landform grade, trails are .007 in. deeper for each 1% change in landform grade).
[4] Cohen's Estimated Effect size (Cohen 1992)

The use-related models (Tables 9 & 10, #1) indicate that use level significantly influences CSA and MI. Using medium use as the reference for dummy variable coding, the high and low use CSA and MI values are significantly different ($p < 0.05$). The beta coefficients for high use trails are positive, indicating an increase in CSA and MI from medium use, while the beta coefficients for low use trails are negative, indicating a decrease in CSA and MI from medium use.

Within the environmental model (Table 10, #2), landform grade is not a significant influence on MI but landform position is ($p < 0.001$). The positive coefficient for fall-line trails reveals that these alignments are deeper (greater MI value) than side-hill trails and this difference is statistically significant ($p < 0.001$). In the CSA model we see similar relationships for landform position (fall-line has positive coefficient indicating higher CSA values than side-hill) and landform grade is also a significant ($p< 0.007$) influence on CSA (Table 9, #2). The positive landform grade beta coefficient indicates that CSA values increase as landform grade increases.
The third model contains managerial factors that can be manipulated through trail design and maintenance (Tables 9 & 10, #3). Of the four factors in this model, only trail grade significantly influences CSA and MI ($p < 0.004$). Trail grade has positive coefficients, indicating that CSA and MI increase with increasing trail grade.

Table 10. Regression modeling to evaluate the influence of use-related, environmental, and managerial factors on soil loss (maximum incision).

Factors	Regression Models[1]			
	(1)	(2)	(3)	(4)
Use-Related				
Use Level:	(0.004)[2]			(0.004)
High	(0.059) 0.695[3]			(0.064) 0.670
Medium	0 (dummy code)			0
Low	(0.091) -0.329			(0.091) -0.323
Environmental				
Landform Grade		(0.061) 0.009		
Landform Position:		(0.001)		
Fall-line		(0.001) 0.549		
Side-hill		0 (dummy code)		
Managerial				
Trail Grade			(0.001) 0.031	(0.000) 0.035
TSA			(0.566) -0.003	
Slope Ratio			(0.790) 0.110	
Borders			(0.490) -0.167	
Adjusted R^2	0.019	0.019	0.035	0.053
Estimated Effect Size[4]	Small	Small	Small	Small

[1] Regressions run with General Linear Model using maximum incision as the dependent variable.
[2] Two-tailed t-test significance
[3] Unstandardized Maximum Incision coefficients, inches
[4] Cohen's Estimated Effect size (Cohen 1992)

The final models (Tables 9 & 10, #4) begin with inclusion of all factors and utilize backwards step-wise selection to remove non-significant factors. However, only two of the seven factors are significant, use level ($p < 0.004$) and trail grade ($p < 0.001$). These overall models indicate that CSA and MI measures of soil loss increase with increasing level of trail use and trail grade.

Adjusted R-squared values reflect the proportion of variability in a data set accounted for by the statistical model. They provide a measure of how well future outcomes are likely to be predicted by a regression model. Adjusted R-squared values for the CSA regression models range from 0.038 for the managerial model to 0.123 for the overall model. Adjusted R-squared values for MI regression models range from 0.019 for the use and environmental models to 0.053 for the overall model. Cohen's *A Power Primer* (Cohen 1992) is used to estimate effect sizes based on these adjusted R-squared values. An effect size is a statistic that conveys the estimated magnitude of a relationship between variables without making any statement about whether the apparent relationship in the data reflects a true relationship in the population. In that way, effect sizes complement inferential statistics such as p-values. Cohen's test statistic for multiple and partial regression models was calculated as: $f = \frac{R^2}{1-R^2}$

Based on Cohen's effect size indices, the effect size estimates for CSA models range from small for the managerial model to small-medium for the overall model (Table 9). The effect size estimates for MI models are all small (Table 10).

Informal Trails

Lakewood: Spatial Patterns

Informal trails mapped in the Lakewood vicinity were consistent with a spatial arrangement common to high-relief topography recreation sites (Figure 16). High slopes tended to concentrate travel in draws and along the edge of the lake. The recreation site anchoring these trails was a heavily used beach landing running down near the center of the eastern edge of the lake. The gullying erosion was observed to be most severe nearest to the lake's edge. Multiple small overlooks were found arranged in the steep slope above the recreation site.

A dense network of highly impacted (CC 5) trails surrounded the recreation site. These trails were highly interconnected (i.e. redundant) and descended the local slope rapidly. Tread conditions were visibly erosive. These trails also connected the recreation site to a network of exploration trails encompassing the entire eastern side of the lake.

The exploration trails commonly decreased in condition class with increasing distance from the recreation site. Where navigation along these trails was most difficult, due to sharp topography at the lake's edge or in dense patches of overhanging vegetation, trail braiding was common. To the south of the recreation site, a comparatively impacted (CC 4) trail followed an old forest road bed southeast to a lake. North of the forest road trail and east of the recreation site, a second, less-impacted network was found to have grown from an access trail running southward.

Lakewood: Trail Conditions

The dense use pattern at Lakewood resulted in comparatively severe trail conditions. Survey data (Table 11) reveal that 344 m (12%) of the 2852 m total lineal extent of informal trails were assigned to condition class 5. The average length of informal trail segments were relatively even across CCs in the Lakewood area. However, the greater number of low CC segments skewed the distribution of typical segments toward lower levels of observed impact. A plurality, 51%, of informal trails in this area was assigned to CC 1 or 2.

Soil loss and gullying is most severe nearest to the lake's edge, leading to concerns for secondary impacts to water quality. One possibility would be to provide formal trail access to this area and improve efforts to close the more eroded informal trails.

Table 11. Summary of informal trail extent by Condition Class at Lakewood.

Condition Class	Segment Count (#)	Mean Length (m)	Linear Extent (m)	%
CC 1	30	27.1	813	29
CC 2	20	31.0	620	22
CC 3	21	30.9	648	23
CC 4	9	47.4	427	15
CC 5	12	28.7	344	12
Totals	92	33.0	2852	100

Bass Harbor: Spatial Patterns

Informal trails mapped in the Bass Harbor area of the park closely followed the shoreline and old forest roads. The network connected the frontcountry recreation sites around Bass Harbor Head lighthouse and the nearby shoreline access trail, along the coastline and around the western head of Ship Harbor, to 102A just west of the Ship Harbor trailhead. Eastward from Bass Harbor Head, the network consolidates rapidly to a well-established shoreline path with occasional inland parallel tracks and trails connecting northward to a local unpaved access road. Numerous short, occasionally steep side trails spur from the shoreline trail down to cobble beaches and wherever localized rock formations appear accessible.

Bass Harbor: Trail Conditions

Informal trail conditions at the westernmost extent of this network were highly impacted (Figure 17). The trails near Bass Harbor Head appeared to serve as high use exploration corridors to the coastline. In isolated locations, these trails exceeded 100% slope and pose a safety concern.

The remainder and majority of this informal trail network was catalogued as lightly impacted, 91% of the network was classed as CC 1 or 2 (Table 12). The inland trails in this area are lightly traveled (CC 1) and in places difficult to follow due to a thick mat of accumulated organic matter. Field staff observed occasional rock cairns and stone road markers indicative of past land use that may serve as orientation points for current users, helping to keep the paths open. Regular use by local dog walkers is apparent. In addition, evidence of squatters (hand-built rock/scrap-wood shelters, litter, etc.) was observed under sheltering foliage inland from the shoreline trail. In numerous locations, cut branches and stumps indicated deliberate maintenance, whether formal or informal, along the shoreline path in recent history. Though limited in lineal extent, the CC 5 trails might be considered for closure due to erosion and safety concerns.

Table 12. Summary of Informal trail extent by Condition Class at Bass Harbor.

Condition Class	Segment Count (#)	Mean Length (m)	Linear Extent (m)	%
CC 1	49	78.3	3838	74
CC 2	16	55.8	893	17
CC 3	5	29.4	147	3
CC 4	8	23.5	188	4
CC 5	9	16.4	148	3
Totals	87	40.7	5215	100

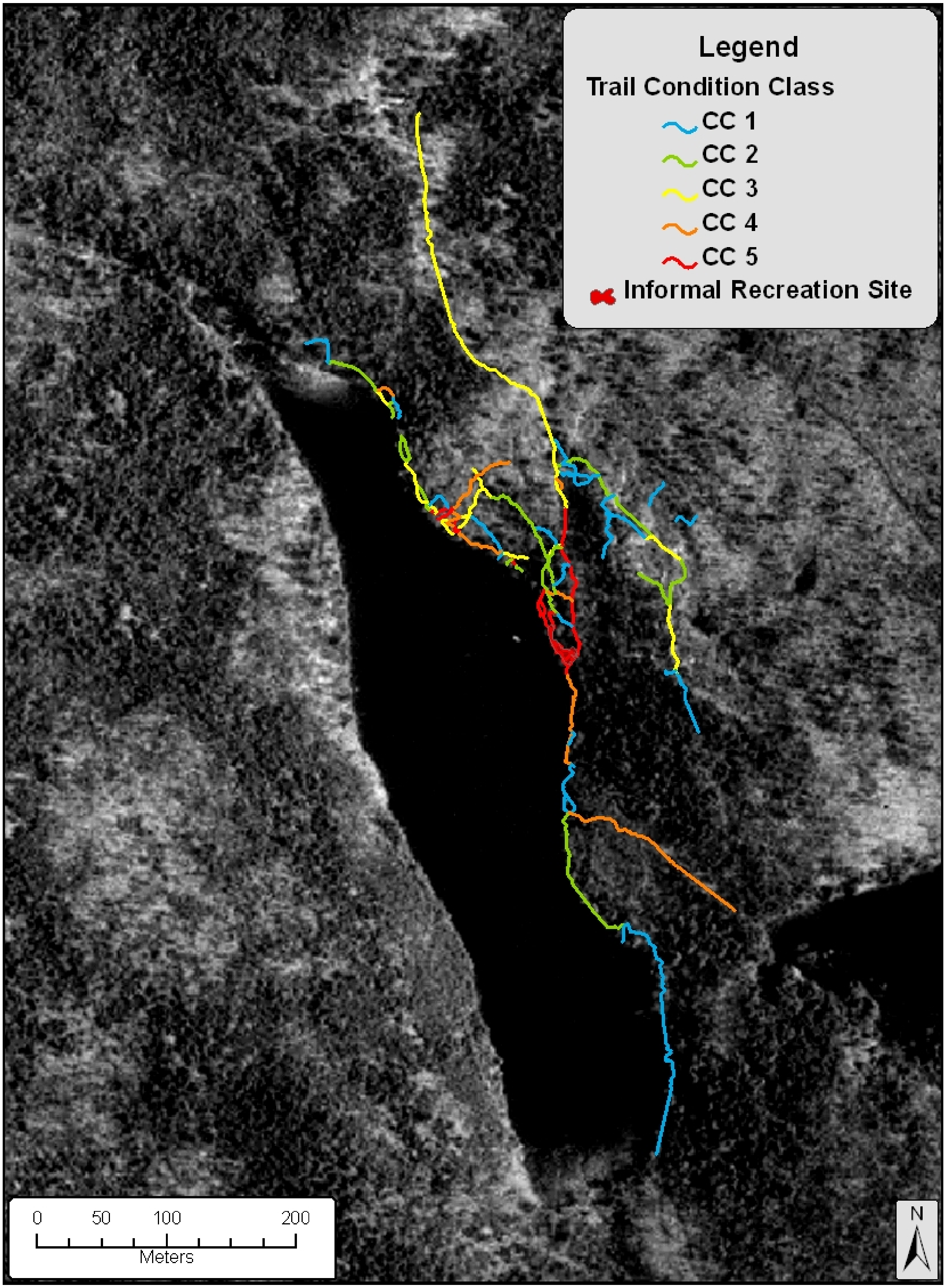


Figure 16. The informal trail network around Lakewood.

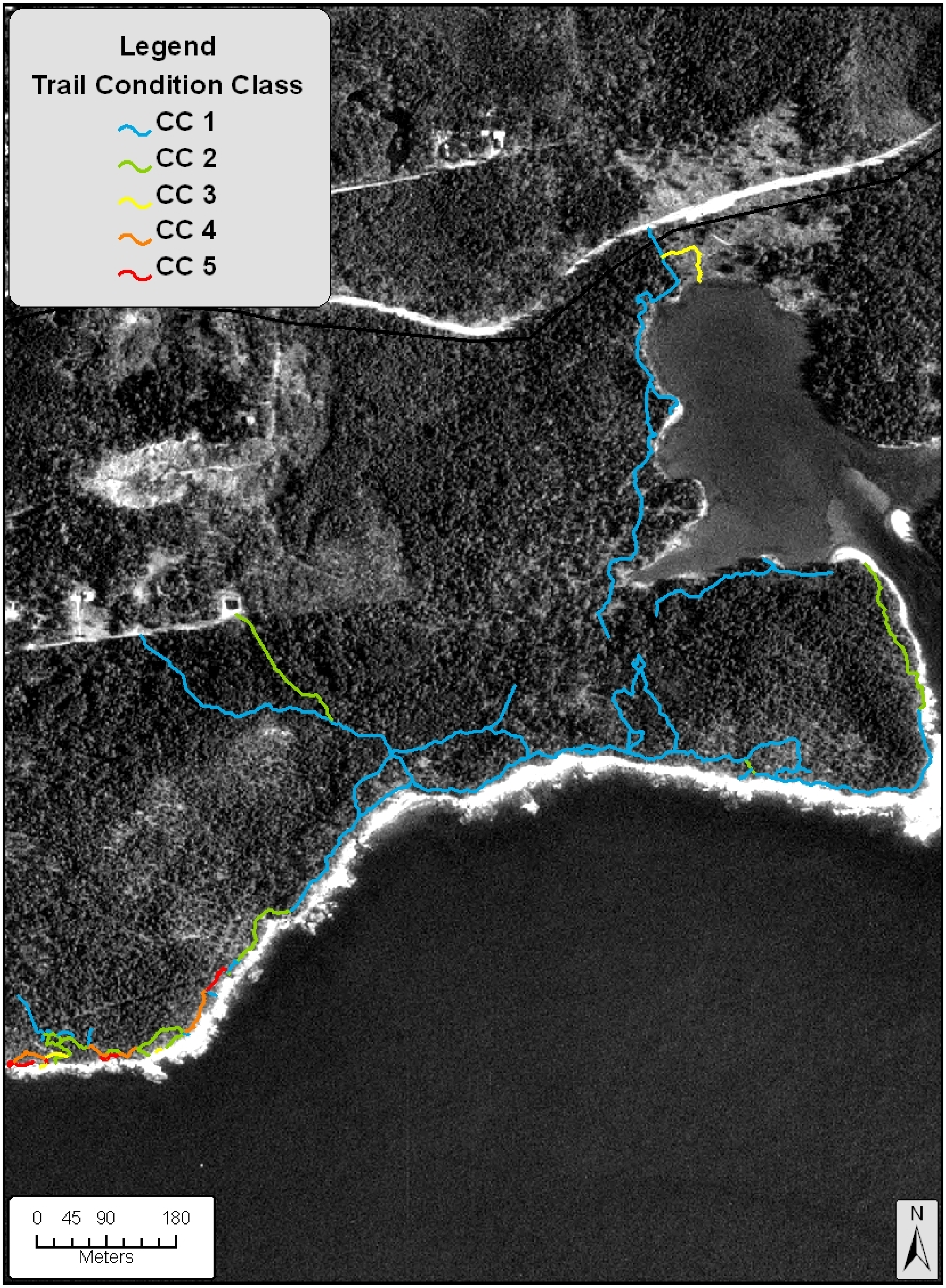


Figure 17. The informal trail network around Bass Harbor.

DISCUSSION AND MANAGEMENT IMPLICATIONS

This section of the report reviews and summarizes the study findings and discusses some implications for management actions that can help avoid or reduce the impacts of visitation on the park's formal trail system and informal trails.

Review and Summary of Findings

Park managers operate under legislative mandates to provide appropriate recreational opportunities while protecting and preserving park resources and natural processes. While a variety of recreational uses, including trail-related activities, are clearly appropriate, park managers must also ensure that they avoid significant impairment of natural and cultural resources. As described in the Introduction section, park managers are charged with applying their professional judgment in evaluating the type and extent of recreation-related impacts when judging what constitutes impairment. This report provides useful information for rendering such determinations and provides a basis for decisions to enhance management of visitors and resources to avoid or minimize recreation impacts.

This research developed and applied state-of-the-art trail condition assessment and monitoring procedures and applied them to the park's formal and informal (visitor-created) trails. A variety of trail condition indicators were identified in consultation with park staff for potential use in future VERP carrying capacity planning and decision-making. Protocols were developed, field-tested and applied with results fully summarized for use in selecting standards of quality. These protocols are included in Appendix 1 for adaptation and use by park staff. Furthermore, park staff accompanied our field staff to witness and learn how to conduct the field assessments during future trail monitoring work.

Management Suggestions

Formal Trails: Resource conditions for the 120-mile MDI formal trail system were quantitatively documented for a variety of indicators, providing baseline data that can inform managers regarding the current condition of their formal trails, guide the selection of indicators and standards, and allow comparison to future condition assessments to evaluate trends over time. Of the impacts assessed, survey results point to trail widening and soil loss as perhaps the two most prevalent and important types of trail degradation affecting the MDI trail system. The following discussion is focused on these two trail impacts.

Mean trail width is a relatively wide 37.7 inches, though many trails are designed with wider widths to support heavy visitor use. The difference between intended vs. actual trail widths was assessed as "trail width difference," with a mean of 5.6 inches indicating that the formal trails are generally 21% wider than intended.

Wimpey and Marion (2010) provide a more extensive evaluation of this indicator, including extensive regression modeling to discover the relative strength of influential factors. This paper provides more insights and guidance for addressing this form of trail impact. Some core findings are that excessive trail width is predominantly a function of human trampling behavior; six types of behavior that contribute to excessive trail widening are described. However, trail widening behaviors can be substantially modified by a number of environmental and managerial factors. A second finding is that sloping terrain adjacent to side-hill trails resists trail widening, with the degree of restriction directly related to the steepness of the landform grade. Fall-aligned trails offer little to no lateral topographic resistance and the lateral dispersion of hikers increases with increasing trail grade. Trails in flatter terrain are also particularly prone to widening, unless prevented by dense woody vegetation.

Finally, the analyses identify tread rugosity (roughness) as an influential factor that causes avoidance behaviors that widen trails when hikers travel along trailsides that offer easier passage (Wimpey & Marion 2010). An important implication is that managers can contain the lateral spread of traffic along trails by adequately addressing excessive erosion, which leads to stoniness, rutting, and exposed roots, and by resolving problems with muddiness. Managers can provide physically challenging trails, but keeping visitors on them requires design and maintenance practices that ensure the provision of a tread that is *more inviting to traffic than the adjacent trailside terrain*. A tread that always appears to the trail user as the most direct or easiest route will likely be used consistently with minimal lateral dispersal of traffic.

To address tread widening in problem areas trail maintainers can strategically place large rocks or cut ends of trees placed perpendicular to the tread to force visitors to the center of widened treads. Low impact education encouraging visitors to walk single file and stay to the center of the trail can also assist. In our analyses, level of trail use and the absence of trail borders were also significantly correlated with trail widening. Managers have limited ability to adjust amount of trail use because the free bus system makes stops at most trailheads, removing parking lot capacity as an attribute that could be manipulated.

Soil loss was assessed for the formal trail system using three measures: mean trail depth (2.1 in), maximum incision (2.6 in), and cross-sectional area (84.8 in^2). If no soil loss is assumed for transects located on ledges (bedrock) then substitute mean values are 0.9 in, 1.4 in, and 36.7 in^2, respectively. However, assuming these more conservative values still yields an aggregate estimate of trail system soil loss of 5681 yd^3 (50 yd^3/mile), or 568 ten cubic yard dump trucks of soil. Relational analyses for this factor revealed the significant influence of level of trail use, trail grade, and trail slope alignment angle. Managers may have little control over level of use but could consider relocations of trail segments that are excessively steep or that are aligned closely to the fall line (landform aspect) of mountain slopes. While trail manuals commonly recommend grades of less than 10-12% to prevent soil loss, our survey found that 31% of the park's formal trails exceed a grade of 15%. Additionally, half of the formal trail system is aligned within 22^o of the fall line, which greatly impedes management efforts to remove water from incised treads. More importantly, 21% of the park's trail system have grades greater than 15% ***and*** alignment angles less than 22^o, revealing that a very large percentage of the trail system is not sustainably designed. We expect that soil erosion would be much higher than assessed were it not for the substantial amount of granitic rock in the soils and the extensive use of rock steps.

Results suggest that relocations should be considered for trail segments with unsustainable designs that currently lack extensive rockwork. Such relocations would also make hiking more enjoyable and safer, though rockwork, improved tread drainage, or closure are options in areas where historic trail alignments may prevent consideration of relocations. Particularly effective trail maintenance solutions include the incorporation of periodic grade reversals (rolling grade dips) within steeper treads that are carrying water (IMBA 2004). A combination of water bars and outsloped treads are additional alternatives (Birchard & Proudman 2000, Marion & Leung 2004). Properly designed grade reversals require no subsequent maintenance but water bars and outsloped treads need to be maintained once or twice each year or they will fail and allow water to run down treads with increasing erosive force.

As an aid to managers in evaluating trails for sustainability and resource conditions, we included an extended table summarizing inventory and impact indicator data by trail groupings provided by park staff (Table 8). These data could be helpful in decision-making by park area or in identifying appropriate indicator standards.

Informal Trails: Protocols for assessing the spatial patterns, lineal extent, and condition of informal (visitor-created) trail networks were also developed and applied, building on earlier work done separately and in collaboration with park staff. The creation and proliferation of informal trails has been a common long-term management problem in the park. These protocols were applied at two locations selected by park staff to provide case examples for evaluating their applicability and utility. Our informal trail surveys at these locations went as planned and provided accurate datasets and maps of the informal trails in the two study areas (Figures 16/17, Tables 11/12).

Informal trails may be considered appropriate under some circumstances to provide visitor access to various park locations not accessed by formal trails. However, when informal trails pass through areas with rare or sensitive flora or fauna, or sensitive cultural/archaeological resources, or are excessively abundant or redundant, they become less appropriate or unacceptable. Informal trails that directly ascend steep slopes and/or will easily erode are less acceptable than trails with a side-hill design. Informal trails prone to muddiness and widening are less acceptable, as are trails that may contribute soils to water resources. These and other factors must be evaluated by park managers before selecting and applying corrective actions. Comprehensive guidance for managing informal trail networks is provided in Appendix 2.

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APPENDIX 1: FORMAL TRAIL MONITORING MANUAL

Formal Trail Condition Monitoring Manual

Acadia National Park
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
- ☐ Field forms- some on waterproof paper
- ☐ Topographic and driving maps
- ☐ Clipboard w/compartment for forms
- ☐ Pencils
- ☐ Tape measure in inches (6 ft)
- ☐ Metal binder clips (2) to attach tape to stakes
- ☐ Line level
- ☐ Measuring wheel or Trimble GPS loaded with sample points, park trails, and data dictionary
- ☐ Compass
- ☐ Tape measure in tenths of feet (20 ft)
- ☐ 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.

1 - Developed by Dr. Jeff Marion, USDI, U.S. Geological Survey, Patuxent Wildlife Research Center, Virginia Tech Field Station, Virginia Tech/ FREC (0324), Blacksburg, VA 24061 (540/231-6603) E-mail: jmarion@vt.edu

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) **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).

9) **Maximum Incision, Current Tread (MIC):** Stretch the fiberglass tape tightly between the two tent stake pins that define the tread boundaries - any bowing in the middle will bias your measurements. This transect line should reflect your estimate of the post-construction, pre-use land surface, serving as a datum to measure tread incision caused by soil erosion, displacement 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. See Figure 2, noting differences in MIC measures for side-hill vs. non-side-hill trails.

10) **Cross-Sectional Area (CSA):** The objective of the CSA measure is to estimate soil loss from the tread at the sample point following trail creation. Soil loss may be due to erosion by water or wind, soil displacement from trail users, or compaction. 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.

Measurement Procedure: On the CSA data form, label a new row with the measuring wheel distance for the transect (e.g., D=600 ft). Place the transect stakes as described under the appropriate situation (a-d below). Starting on the left side record a 0 for the 1st mark on the line (V_1, at 0 ft), followed by the measurement for the 2nd mark (V_2 at 0.3 ft). The standard interval for these measures is 0.3 ft (3 5/8 in) but for wide trails alternative intervals can be used (e.g., 0.5 ft or 1.0 ft) – if alternative intervals are used *note the interval value* on the CSA form. Take all vertical measures *perpendicular* to the transect line down to the ground surface recording values to the nearest 1/4 in (e.g., .25, .5, .75). Record the values on the data sheet next to their labeled numbers (e.g., V_1, $V_2 \ldots V_n$). Continue measuring each vertical until you reach the far side of the trail and obtain a measure of 0 when the original (non-eroded) ground is reached. ***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. Contact Jeff Marion for a spreadsheet that calculates CSA for this data.

a) Direct-ascent trails, recent erosion: Refer to Figure 2a and follow these procedures. Place two stakes and the transect line to characterize what you judge to be the pre-trail or original land surface. Place the left-hand stake so that the "0" mark on the transect tape will fall on what you believe was the "original" ground surface but at the edge of any tread incision, if present (see Figure 2a). The tape has been sewn to allow two stake placement options to accomplish this. The transect incision value you record for the 1st mark (V_1) must be 0. Stretch the transect tape 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 line cannot be configured properly at the sample point due to rocks or obstructing materials that cannot be moved, then move the line forward along the trail in one-foot increments until you reach a location where the line can be properly configured.

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) – see guidance in 16a above. 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 1st left-side measure (V_1) must be 0. 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 (see Figure 3). 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 (generally less than 6 inches in height). 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 marks on the bubble glass that allow you to level and then configure the tape as a 3% outslope (a 1 in. drop over 33 in. – see table at right of offset values from level) to standardize the line placement. A 3% outslope is used because actual tread construction may have been somewhat less than 5%, and 3% provides a more conservative estimate of soil loss. It is generally easier and more accurate to

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

place the downslope stake first and configure the line to a 3% outslope to reveal where the uphill stake should be placed. Measure the left-hand stake as transect 1 with a 0 measure and also record a final transect beyond the right-hand stake with a measure of 0.

d) <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). 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 2d). 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.

Note: If the line cannot be configured properly at the sample point due to rocks or obstructing materials that cannot be moved, then move the line forward along the trail in one-foot increments until you reach a location where the line can be properly configured.

11-20) **<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:	<u>Naturally-occurring</u> 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:	<u>Human-placed</u> (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:	<u>Human-placed</u> wood (water bars, bog bridging, cribbing).
O-Other:	Specify.

21) **<u>Trail Grade (TG):</u>** 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. After data entry convert to percent slope = [tan (degrees)] x 100.

22) **<u>Landform Grade (LG):</u>** Assess an approximate measure of the prevailing landform slope in the vicinity of the sample point. Follow the one-person procedure described in #22.

23) **<u>Trail Slope Alignment Angle (TSA):</u>** 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, 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).

24) **<u>Secondary Treads (ST):</u>** 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.*

25) **<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).

Collect all equipment and move on to the next sample point.

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.

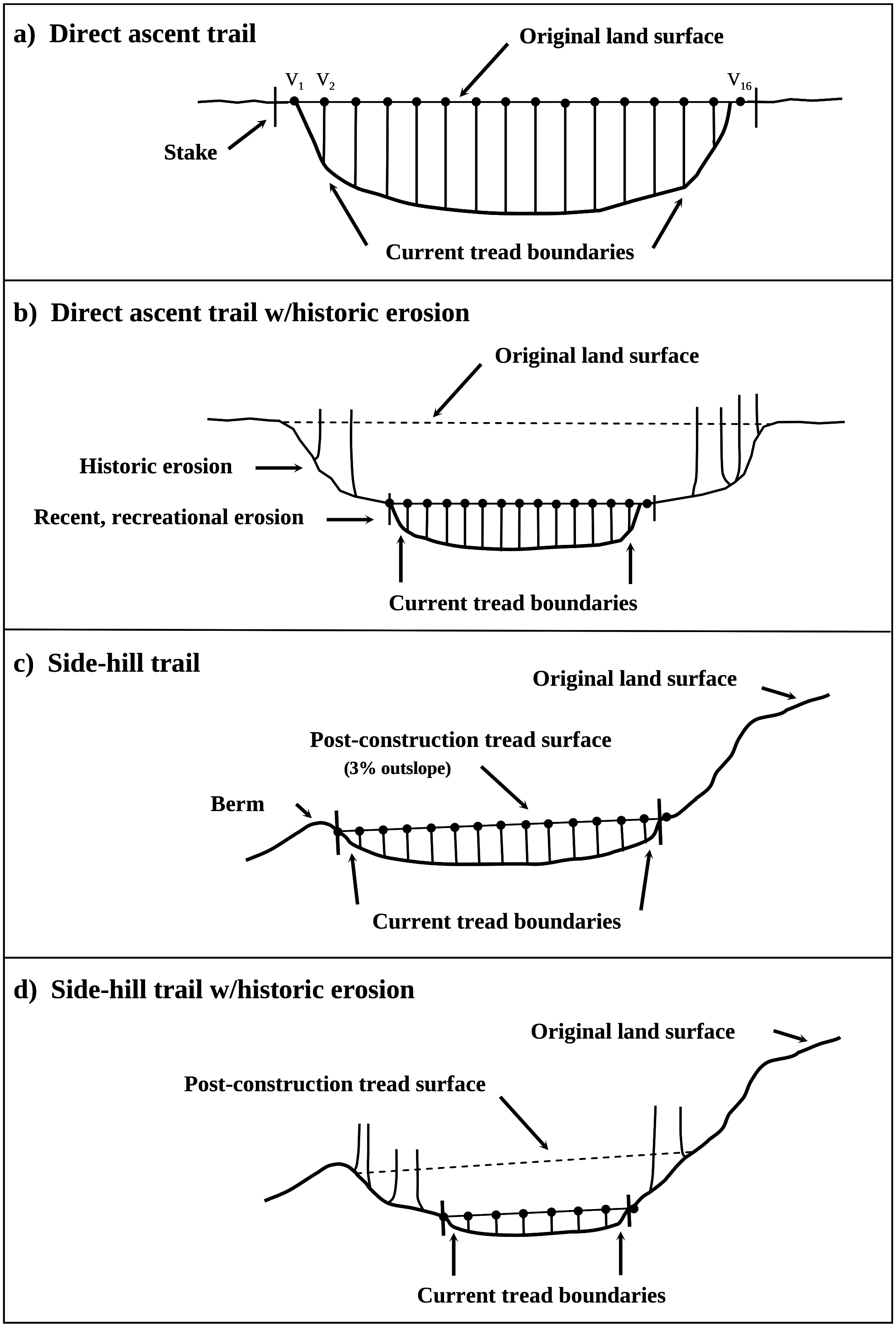

Figure 2. Cross sectional area (CSA) diagrams illustrating alternative measurement procedures for direct ascent trail alignments (a & b) vs. side-hill trail alignments (c & d) and for relatively recent erosion (a & c) vs. historic erosion (b & d).

Cross Sectional Area Form

Trail Segment Code ________ **Trail Name** ______________________________

CSA		CSA		CSA	
Transect (in)	**Area**	**Transect (in)**	**Area**	**Transect (in)**	**Area**
D=					
V_1=					

Point Sampling Form

Trail Segment Code ________ **Trail Name** ______________________________ **Surveyors** ______________

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

Starting Point: **UTM:**______________________________

Ending Point: **UTM:**______________________________

Dist	SH	ST	TG	LG	TSA	TW	Tread Substrate Characteristics	MIC	CSA
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							0 10 20 30 40 50 60 70 80		

Dist = Wheel Distance
SH = Sidehill (Y, N, U)
TW = Tread Width
TG = Trail Grade
LG = Landform Grade

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

S = Soil G = Gravel
L = Litter RT = Roots
V = Vegetation W = Water
R = Rock WO = Wood, human-placed
M = Mud O = Other (Specify)

APPENDIX 2: INFORMAL TRAIL MONITORING MANUAL

Informal Trail Monitoring Manual

Acadia National Park

Description of Procedures

Developed by Jeremy Wimpey, Jeff Marion, and Logan Park
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Contact: jmarion@vt.edu, 540-231-6603

Introduction

The creation and proliferation of informal (visitor-created) trails can directly impact sensitive plant communities, rare or endangered flora and fauna, and wildlife habitats. For example, a small patch or population of rare plants may be eliminated by trampling, habitat changes caused by visitor use, or through competition from non-native species introduced by park visitors. Recreationists seeking to access scenic overlooks, water resources, or merely to explore, often trample vegetation sufficiently to create extensive informal trail networks. Such unplanned trail networks generally receive no environmental reviews and resource degradation is often severe due to their lack of professional design, construction, and maintenance. While some degree of visitor impact is unavoidable, excessive trail impacts threaten natural resource values, visitor safety, and the quality of recreational experiences.

Objectives

These protocols are designed to document the number, lineal extent, spatial distribution, area of trampling disturbance, and resource condition of all informal trails within a specified study area. Assessment procedures are efficiently applied through walking surveys that employ sub-meter accuracy Global Positioning System (GPS) units providing field staff a paperless method for collecting trail inventory and resource condition data. When periodically collected over time, these data assist with the monitoring of onsite resource conditions and provide long-term documentation of the existence, location, and condition of informal trails. The data also provide supporting information for management decisions, such as to evaluate which informal trails should be closed or left open, and later to evaluate the success of management efforts to close selected trails, prevent the creation of new trails, or prevent further deterioration of existing trails.

Guidance

This collection protocol should be performed at the end of peak season visitation, i.e., mid-August, when evidence of visitor use is most pronounced and to minimize seasonal variations in trail conditions. Collection should be done at multi-annual intervals (e.g., every three to five years). This schedule assists in locating trails that may emerge or change conditions later in the season. It is important to perform the collection consistently in time across each year to provide management with comparable data.

Materials

- Trimble GeoXT GPS[1]
  - Loaded with: 1) Informal Trail (IT) Data Dictionary, and 2) formal trail layer
    - Contact Dr. Jeffrey Marion, U.S. Geological Survey, Virginia Tech Field Station (FREC), jmarion@vt.edu for replacement layers and data dictionaries
  - Stylus
  - Hurricane antenna and connecting lead
  - Trimble backpack and spare external battery
- Tape measure (6ft auto-retracting)
- Paper maps showing formal trail system
- Pens and notebook

1 – Use the most accurate equipment available. Greater accuracy in data collection translates to more accurate, objective, and efficient GIS editing work.

Methods

Survey staff should be familiar with study area and its visitor use patterns, particularly where visitors are most likely to depart formal trails and potential off-trail destinations. Scheduling field surveys during times of optimal satellite constellations may be necessary for some areas. Begin work by selecting an area (sub region of the study area) on the paper map to search. Use features such as trails, roads, and streams, along with prior survey data and personal knowledge, to divide the area into manageable units. Prior data should be used as a guide but not as an authoritative catalog of where informal trails will be found and mapped. To ensure that all informal trails are located, walk all formal trails and search the areas adjacent to each trail for informal trails.

Where possible, do not assess trails created and/or used predominantly by wildlife (e.g., deer). Such trails are generally narrow and go under low-hanging branches that would obstruct human traffic. Be spatially aware and thoroughly search along/near formal trails and features for areas that are likely to draw visitors off the formal trail network (e.g., vistas, water bodies, geographic features of interest, historic structures). In particular, beware of informal trails that depart a formal trail on resistance surfaces (e.g., rock, gravel, bare soil, grass) that may hide the beginning of in informal trail. Some random searching and walking transects across off-trail areas, particularly near any features of interest, are necessary to locate and map all informal trails.

When an informal trail is located, begin an informal trail segment using the IT data dictionary. Use the Condition Class descriptors below to determine and record the appropriate condition class. Do not begin walking the trail segment until the GPS has successfully recorded its first position fix. Walk the trail while collecting the feature until it reaches a junction or changes condition class. Assess and record the segment's average trail width (see below) and then close the segment in the GPS.

Trail width is defined as the most visually obvious outer boundary of trampling-related disturbance that receives the majority (>95%) of traffic. These boundaries are defined by pronounced changes in ground vegetation height (trampled vs. untrampled), cover, composition, or, when vegetation cover is reduced or absent, by disturbance to organic litter (intact vs. pulverized) or lichen. Include any secondary parallel treads within this assessment only when they are not differentiated from the main tread by strips of less disturbed vegetation or organic matter. See Figure 1 for photographs illustrating these trail boundary definitions.

When in areas or times with poor GPS accuracy, stop at trail junctions to record an averaged IT trail junction point. These points will improve the accuracy of GIS data editing.

After thoroughly collecting all informal trails within your sub region, make a notation on you paper map to indicate it has been collected and move on to another sub region.

Decision rules for Collecting Informal Trail segments

A condition class change that occurs for less than 2 meters (approximately 6 feet) can be ignored (i.e. collect it as one segment and assign the dominant condition class to the segment). Be careful to try to avoid collecting animal trails. These trails will be narrow and have low hanging branches/vegetation. Use your judgment and look for signs of human and animal use (footprints, litter, deer browse, etc.).

Condition Class Structure

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.

Condition Class rating descriptions applied to informal trails.

Surveying Tips

- Use the pause and resume (log) capabilities of the GPS to prevent collecting extraneous points at the beginning and end of a segment. Pause the logger when not moving; restart it as you resume movement.

- Working in pairs or using flagging tape and or pin flags will help when the IT network is very dense. Flag sub regions on the ground and work through them individually.
    - When working a dense network work small sub areas and utilize flags and landmarks to delineate them; when collection has been completed within one

flagged sub area, establish an adjacent sub area and collect it (e.g., 50-100 m long on one side of a formal trail).

- Collect IT anchor points when needed to aid in tying trail junctions to a specific location. Use Trimble's nest feature option.

- Use the formal trail layer and paper maps as a reference.

Data Download and Backup

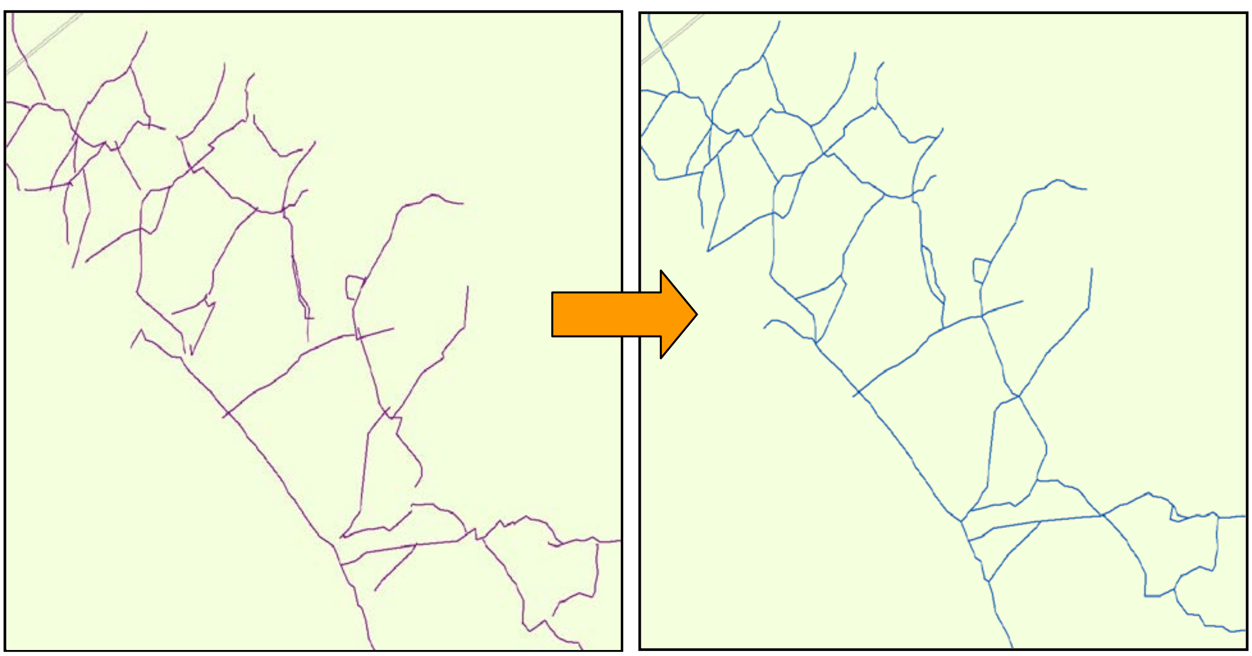
- When finished collecting for the day, close the rover file on the Trimble GPS.
- Connect the GPS to a computer with Pathfinder Office software (work within the preexisting project directory for the current collection).
- Transfer the rover files to the computer.
- If an internet connection is available, download the differential correction files that correspond to all new rover files and differentially correct them.
    - Designate the source base station as the closest available geographically.
    - Review the correction report as well as the corrected files for any errors or processing problems. Open the files in GIS to visually inspect them each day.
    - Ensure that the data were not removed during the correction procedure (e.g., due to missing base station data, high PDOP, etc).
    - Correction files that are not immediately available are generally made available within a week or two.
- Backup all data on a separate HDD and document all necessary metadata.
- Recharge the GPS and external battery.
- Keep a written field notebook record of all fieldwork, including field staff names, search areas, dates/times, and computer filenames.

Editing Data

Data should be post-processed (differentially corrected and converted to GIS appropriate format) using GPS software (e.g., Trimble's Pathfinder Office with conversion to ArcMAP Shapefiles). Merge output files into a single file representing the Informal trail network.

Informal trail data requires editing due to the nature of GPS data collection. GIS staff should edit the data to clean up and improve the accuracy of the informal trail network. Tips for doing this work:

- Use imagery and ancillary GIS datasets to help visualize the local environment.
- Move trail segment endpoints (minimally) to establish connectivity to other informal segments, recreation sites, and formal trails.
    - Use the anchor points layer for establishing junction locations.
- Use snapping and zoom tools to assist.
- Once the network is close, a "clean" or "build" procedure can be used (adjust fuzzy tolerance and dangle length as needed).



Before Editing | After Editing

Figure 1. Trail width is defined as the most visually obvious outer boundary of trampling-related disturbance that receives the majority (>95%) of traffic. These boundaries are defined by pronounced changes in ground vegetation height (trampled vs. untrampled), cover, composition, or, when vegetation cover is reduced or absent, by disturbance to organic litter (intact vs. pulverized) or lichen.

Data Dictionary

Informal Trail:
LineFeature

Label1=Average Width
Condition Class: Menu; Normal, Normal
1 2 3 4 5 Other

Average Width=Numeric, Decimal Places=0
Minimum=1,Maximum=144,DefaultValue=8 Normal, Normal

Segment#:
Numeric, Decimal Places=0
Minimum=0, Maximum=500, Default Value=1, StepValue=1 Normal, Normal

Comment:
Text, Maximum Length=30 Normal, Normal

IT Anchor Point:
Feature

Label1=Number
Label2=Comment

Number=Numeric Decimal Places=0
Minimum=0,Maximum=500, DefaultValue=1, StepValue=1 Normal, Normal

Comment:
Text, Maximum Length=30 Normal, Normal

APPENDIX 3: GUIDANCE FOR MANAGING INFORMAL TRAILS

Guidance for Managing Informal Trails

Jeff Marion, USGS Research Scientist
(jmarion@vt.edu, 540-231-6603)

The development, deterioration and proliferation of visitor-created informal trails in protected areas can be a vexing management issue for land managers. Formal trail systems never provide access to all locations required by visitors seeking to engage in a variety of appropriate recreational activities. Traveling off-trail is necessary to engage in activities such as nature study, fishing, or camping. Unfortunately management experience reveals that informal trail systems are frequently poorly designed, including "shortest distance" routing with steep grades and alignments parallel to the slope. Such routes are rarely sustainable under heavy traffic and subsequent resource degradation is often severe. Vegetation impacts include trampling damage leading to changes in species composition, potential introduction and dispersal of non-native plants, and the loss of vegetation cover. Soil impacts include the pulverization and loss of organic litter, and exposure, compaction, and erosion of soil. Soil deposition in streams, disturbance to wildlife, and damage to historic resources are also possible. Creation of multiple routes to common destinations is another frequent problem, resulting in "avoidable" impacts such as unnecessary vegetation/soil loss and fragmentation of flora/fauna habitats.

This guidance is provided to assist land managers and volunteer trail maintainer organizations in evaluating informal trail impacts and in selecting the most appropriate and effective management responses.

Adopt a Decision-Making Process

The management of informal trail networks can benefit from application of a planning and decision-making process or framework that includes public dialogue and input. Decisions regarding impact acceptability and the selection of actions needed to prevent recreation-related resource impacts fall into the domain of carrying capacity decision-making. The NPS defines carrying capacity as "the type and level of visitor use that can be accommodated while sustaining the desired resource and visitor experience conditions in the park" (NPS 2006). The NPS applies the Visitor Experience and Resource Protection (VERP) decision-making framework (NPS 1997), while the U.S. Forest Service applies the Limits of Acceptable Change (LAC) framework (Stankey *et al.* 1985).

These formal frameworks direct managers to prescribe objectives for biophysical and social conditions they intend to achieve for specific park zones. Numerical standards of quality are established for each indicator and zone to define the critical boundary line between acceptable and unacceptable conditions, establishing a measurable reference point against which future conditions can be compared through periodic monitoring. These frameworks incorporate an adaptive management decision process, whereby managers can apply actions, evaluate their success, and when needed, apply alternative actions as a follow-up until management objectives are achieved. A simplified framework known as Protected Area Visitor Impact Management (PAVIM) employs an expert panel and problem analysis process (**Error! Reference source not found.**) that requires less data (Farrell & Marion 2002). The problem analysis process, which is particularly applicable and useful in informal trail management decision-making, is described below.

Problem Analysis Process

Assemble a team of knowledgeable and experienced individuals with expertise in recreation resources management, visitor management, social science, site and trail management, natural resource management, and interpretation. Visit the site where the impacts or problems are occurring and apply this problem analysis process to guide discussions.

Identify and Evaluate the Problem

The problem analysis begins by developing the group's collective knowledge of the area, amounts and types of recreational uses, and the resource and social problems currently present. Group members most knowledgeable about these topics are asked to share their knowledge with the group. The sharing of differing perspectives, land management agency, trail club, recreation representatives, is encouraged. The significance of the problems and degree to which current conditions are unacceptable are considered when deciding whether management actions are needed. Next, participants with the longest experience in the area are asked to relate the history of the problems or impacts. Previous management actions are described and their effectiveness discussed and evaluated, including why implemented actions were or were not effective.

The core of a good problem analysis is a thorough evaluation of a problem's underlying causes and identification of factors that influence impact severity. For example, substantial off-trail traffic may be the cause for excessive vegetation loss but fragile ground vegetation and poorly marked or maintained formal trails may significantly contribute to the creation of unacceptably extensive or impacted informal trails. The relative influence of three groupings of factors: use-related, environmental, and managerial, should be examined. An improved understanding of these causes and factors are essential to evaluating alternative actions and selecting effective actions.

Identify and Evaluate Strategies and Actions

Step two involves brainstorming by team members to list and then evaluate a diverse array of management strategies and actions. Following list development, study team discussions should focus on careful evaluations of the advantages and disadvantages of each action. A number of important attributes should be considered, including potential effectiveness, management feasibility, costs to visitor freedom and satisfaction, expected visitor compliance, and others as appropriate.

The final step is selecting one or more preferred actions suggested for implementation. Careful consideration of the history of impacts and their management, the desired resource and social conditions for the area, and factors which either cause or influence impacts can help guide more objective and effective decision-making. Management objectives or desired condition statements will suggest the appropriateness of alternative actions relative to the natural, social, and managerial settings of the zone the area is situated within.

Generally, initial actions are feasible, have a low "cost" to visitors, and are judged to have a good chance at effecting the desired change in conditions. For example, indirect actions such as education or site maintenance should be considered before regulatory or site development actions as they are less obtrusive and do not compromise visitor freedom. More restrictive, expensive, and/or obtrusive actions are generally deferred until justified by the failure of one or more preceding actions. However, severe or unacceptable impacts may warrant bypassing such light-handed efforts in favor of actions necessary to achieve more effective or immediate results. Alternative actions should be identified for potential implementation in the event that initial actions are ineffective.

For each action, identify likely individuals or organizations responsible for implementing the action and describe the necessary resources they will require. An implementation schedule should also be developed and efforts to obtain funding and staff initiated. At this time it is also useful to consider how a planned action should be monitored for evaluating effectiveness. For example, an accurate GPS survey of informal trail networks with condition class assessments provides a baseline for future comparison and should be conducted prior to implementing corrective actions.

Table 1. Problem analysis for managing resource and social impacts related to visitation.

I. Identify and Evaluate the Problem

- ***Describe area and use(s)*** **-** provide background information about the area, facilities, and visitor use.
- ***Describe problem(s)*** **-** briefly describe the facility, resource and social impact problems that are occurring.
- ***Problem significance*** **-** consider if and why the impacts are significant or unacceptable to land managers and protected area visitors
- ***Previous management actions*** **-** describe the history of the problems and previous actions; discuss the effectiveness of these actions and why they did or didn't work.
- ***Causes and influential factors*** **-** discuss the underlying causes for the impacts and the role of non-causal but influential factors that may intensify impacts. Consider use-related factors (type and amount of visitor use, visitor behavior and motives, use density), environmental factors (soil and vegetation type, environmental sensitivity, topography), and managerial factors (siting, design, construction, and maintenance of facilities, visitor management).

II. Identify and Evaluate Strategies and Actions

- ***List potential strategies and actions*** **-** create a comprehensive list of appropriate and potentially effective management strategies and actions. Strategies are broad approaches (e.g., modify visitor behavior, manage sites and facilities) and actions are the specific means used to implement a strategy (e.g., educate visitors, relocate campsites).
- ***Evaluate strategies and actions*** **-** discuss and evaluate the following attributes for each strategy and action: potential effectiveness, management feasibility (cost, staffing, long-term maintenance), advantages/disadvantages (e.g., costs to visitor freedom), expected visitor compliance, etc.
- ***Formulate recommendations*** **-** through group discussion, develop and write recommendations that reflect the group's consensus views. Describe the recommended action or group of actions to implement first and what might be tried next if these are ineffective.

Problem Definition: For informal trail management decision-making, an inventory of the informal trail network within an area of management concern is particularly useful. If GPS devices and expertise is available, a simple inventory technique is to conduct a walking GPS survey, provided the terrain and forest canopy permit accurate GPS use. GIS software can input, map and analyze the data, providing a visual display of the informal trail network relative to designated trails, roads and other resource features. Computation of the lineal extent of the informal trail network is also possible. If GPS devices cannot be used then an inventory can be made by hand-sketching informal trails onto large-scale maps with lengths assessed by pacing or a measuring wheel.

Where possible, managers may also wish to consider various options for assessing the condition of the informal trails. Many options, ranging from simple condition class evaluations, to trail width and depth measurements, or detailed assessments of soil and vegetation loss are possible. Guidance for assessing trail conditions may be found in the scientific literature (Cole 1983, Leung & Marion 2000, Marion & Leung 2001). Some rapid assessment "condition class" options are included at the end of this document or contact the author for examples of alternative monitoring protocols and manuals. An objective assessment of informal trail conditions can produce quantitative data for indicator variables that can be summarized to characterize current trail conditions, or when replicated, to monitor changes in trail conditions over time. Such data can be used in the previously described formal or informal adaptive management decision-making frameworks.

Evaluate Impact Acceptability: The acceptability of informal trail impacts should be evaluated according to park or management zone objectives. Informal trails located in pristine areas where preservation values are paramount are less acceptable than when located in areas that are intensively developed and managed for recreation use. Trails in areas with sensitive cultural and archaeological resources are particularly unacceptable if they threaten such irreplaceable resources.

Environmental factors: Informal trails located in sensitive or fragile plant/soil types, near rare plants and animals, or in critical wildlife habitats are less acceptable than when located in areas that are resistant to trampling damage and lack rare species. Informal trails that directly ascend steep slopes and/or will easily erode are less acceptable than trails with a side-hill design. Informal trails prone to muddiness and widening are less acceptable, as are trails that may contribute soils to water resources.

Use-related factors: Why is a trail in a particular location and what are the visitors trying to access? Which recreation activities are most responsible for creating informal trails? What are the motives responsible for off-trail hiking? Are some impacts avoidable? For example, informal trail impacts related to a poorly marked formal trail or that result from visitors trying to circumvent muddiness or severe erosion are more easily avoided and should be targeted first. It is not uncommon to find several "duplicative" informal trails in close proximity to each other accessing a common destination. Impacts caused by visitors seeking to shortcut a longer, more resistant route are unacceptable, as are impacts caused by visitors who could alternately access their intended destination by staying on resistant durable surfaces (e.g., rocks or gravel) (www.LNT.org). Informal trails resulting from illegal or inappropriate types of uses are less acceptable than if they are caused by permitted uses.

A careful consideration of these and other relevant factors (e.g., visitor safety) can assist managers in making value-laden decisions regarding the acceptability of informal trail impacts. The acceptability of these impacts, in turn, guides decisions about which trails should be left open, rerouted, or closed, and selection of appropriate and effective management interventions.

Selection of Management Strategies: The problem analysis process can assist managers in considering and evaluating a diverse array of potential management strategies and actions. Note that some degree of degradation to natural resources is an inevitable consequence of recreation use, requiring managers to balance recreation provision and resource protection mandates. Roads and formal trails can never provide complete access to the locations visitors wish to see, hence, some degree of informal trail development is inevitable and must be tolerated. The challenge for managers is to evaluate the impacts in light of recreation provision and resource protection objectives, and apply professional judgment to determine which impacts are unacceptable and require management action.

The following section describes four general strategies for managing informal trail impacts: 1) Improve management of formal trails, 2) Ignore or formalize informal trails, 3) Maintain informal trails, and 4) Close and restore unacceptable trails,.

Improve Management of Formal Trails

If formal trail problems are contributing to the development of informal trails, then addressing such problems is generally one of the more effective and efficient options available to managers. Four problems are common. Make sure that formal trails are well-marked in some distinctive fashion so that visitors can clearly distinguish between formal and informal trails – this is often very confusing to most visitors. In rocky areas, paint blazes may be needed on rocks rather than trees because the terrain demands constant attention to the immediate trail tread. "Overblazing" or clearly defined trail borders (e.g., spaced rocks, logs, or scree walls) may be necessary in some tricky areas. Boardwalks, low symbolic fencing, or higher rustic fencing are more effective but more visually obtrusive and costly. The treads of formal trails should be the most attractive location for walking, maintained to be free of muddiness or deeply eroded ruts with exposed roots and rocks. When braided or multiple parallel treads occur managers should define a single intended tread throughout.

Ignore or Formalize Informal Trails

Some informal trails may have reasonably sustainable design attributes and access locations, such as vistas or campsites (hikers), water resources (fishermen), or cliffs (climbers) that are acceptable to land managers. When visitor access to these locations is appropriate, such trails should generally be left open as informal trails or even designated and managed as formal trails. They serve an important resource protection function by concentrating visitor traffic on a narrow tread and protecting adjacent vegetation from trampling damage. Recreation ecology studies have consistently found a curvilinear relationship between the amount of traffic and trampling impacts (Leung and Marion 2000). The majority of trampling impact occurs with relatively low levels of trampling; once a trail is established, further trampling impact is greatly minimized by a "concentration" strategy that focuses all further traffic to its barren tread. An alternate "dispersal" strategy is only effective under conditions of very low use and/or when traffic can be confined to durable substrates (e.g., rock, gravel) or vegetation (grasses/sedges).

Sometimes a portion of such informal trails may require a reroute to improve the sustainability of an alignment, such as a very steep section aligned with the fall-line (parallel to the landform slope). An experienced trails professional should conduct a review and provide recommendations for informal trails left open to use. Generally trail alignments should favor side-hill over fall-line alignments, avoid grades over 15%, and favor rocky substrates and non-vegetated or grassy groundcover. As with formal trails, leaving an informal trail with a poor "impact susceptible" alignment is rarely a preferred long-term solution. Site development actions, such as graveling or installation of water bars and rock steps, could be applied but these are generally less appropriate on informal trails and would be unnecessary on a well-designed alignment. In most instances, relocation to an improved alignment will be a more cost-effective and sustainable long-term solution, even though pristine terrain is affected.

Due to the relatively poor trail design skills of visitors, it may even be necessary to replace several non-sustainable informal trails with a new well-designed informal or formal trail (with appropriate environmental reviews). An objective evaluation of the aggregate or cumulative impacts, including the total area of trampling disturbance and soil loss, will generally support such a decision. However, this option should only be attempted when managers are relatively certain of their ability to effectively close the pre-existing informal trails.

Maintain Informal Trails

Historically, most park managers have not maintained informal trail networks. However, extending maintenance work to those trails with reasonably sustainable designs left open to use can substantially reduce impacts. For example, managers can piece together a single sustainable route in an area with numerous braided trails and trim obstructing vegetation, subtly enhance tread drainage, or install natural-appearing rockwork on steep slopes. These actions will effectively encourage use and reduce impacts on the sustainable route while reducing use and encouraging natural recovery on alternate informal trail segments. Additional actions, discussed in the following section, can be applied to discourage their continued use.

Close and Restore Unacceptable Trails

Informal trails with poor, non-sustainable design attributes, trails that threaten sensitive resources, or unnecessary trails with duplicative routings should generally be closed and rehabilitated. Managers should recognize that successful trail closures and restoration are rare and require substantial and sustained management effort. The principal reason for low success rates is that while trampling impacts occur rapidly with low levels of use, vegetative and soil recovery occurs very slowly and complete recovery is prevented unless nearly all traffic is removed from treads for several consecutive years. A substantial restoration program involving the addition of soil and plantings of native species, with watering as needed to ensure survival, can hasten natural recovery. However, care must be taken to apply such intensive work only when managers are reasonably certain that effective measures are in place to prevent further trampling of the restoration work.

Selection of Management Actions: An adaptive management program involving education and site management actions is suggested when implementing strategies. Management experience and research have demonstrated that integrating site management and educational actions consistently achieve the highest rates of success. Site management actions are needed to mark and keep visitors on formal trails or to block or hide informal trails; educational actions are needed to inform visitors of the impacts associated with off-trail traffic and what managers would like them to do to protect natural and cultural resources. Visitors frequently misunderstand site management actions that lack signs placed to convey information about impacts of concern and management intent. In the absence of site management actions, visitors may choose to disregard a prompter sign if a well-used informal trail branches off to what looks like an appealing vista.

Educational Actions

An educational component is often critical to communicate a clear rationale for an action – for example, that significant resource impacts can occur in some areas if visitors travel off designated trails. A message with a rationale should be followed by a plea for visitors to remain on formal trails, which need to be clearly designated through site management actions (e.g., blazing, symbolic markers, cairns) to distinguish them from informal trails. Social science research and theory has found that signs with a compelling rationale and clear behavioral plea are more effective than simple "do" and "do not" messages (e.g., "Please Stay on Designated Trails to Preserve Sensitive Vegetation") (Cialdini 1996, Cialdini *et al.* 2006, Johnson & Swearingen 1992, Marion & Reid 2007, Vande Kamp *et al.* 1994, Winter 2006). Such literature should be consulted to improve the efficacy of educational messaging.

Some principal goals that educational efforts seek to communicate include: 1) trampling impacts represent a significant threat to resource protection in some areas, 2) that off-trail traffic has created informal trails that managers would like to close and restore, 3) remaining on formal trails avoids these impacts, 3) formal trails can be distinguished from informal (visitor-created) trails by distinctive markings, and 4) even small amounts of continued traffic prevents the recovery of informal trails that managers are seeking to close and restore. Unfortunately, as you might expect, this is a lengthy and complex educational message that is challenging to communicate effectively. Research suggests that more complex messages are more effectively communicated personally, rather than on signed or in brochures. Regardless, examples of signs that seek to accomplish these objectives and that have received NPS approval for use are depicted in Figure 1. Note the inclusion of the "no-step" icons that communicate the message with just a glance and are understandable by children and non-English speaking visitors. Generally the larger informative signs are placed in conspicuous locations near trailheads and the more numerous "prompter" signs are placed just beyond junctions with informal trails.

Site Management Actions

A variety of site management actions are available for closing informal trails. Close lightly used trails by actions that naturalize and hide their tread disturbance, particularly along initial visible sections where visitors make the decision to venture down them. Effective actions include raking organic debris such as leaves onto the tread, along with randomly placed local rocks, gravel, and woody debris designed to naturalize and hide the tread. These actions also lessen soil erosion and speed natural recovery. On trails that have been effectively closed, transplanting plugs of vegetation at the beginning of wet seasons can hasten natural recovery. Revegetation work conducted before successful closure is achieved can be a frustrating waste of time and materials if visitors continue use of the trail and trample the transplanted vegetation.

Figure 1. Examples of informative trailhead sign (left) and trailside prompter signs that can assist management efforts in closing informal trails.

For well-used trails, such work generally cannot fully disguise the disturbed substrates and vegetation so additional measures are necessary for effective closures. Construct a visually obvious border along the main trail, such as a row of rocks or a log, to communicate an implied blockage for those seeking to access the closed trail. Alternately, embed large rocks or place large woody materials or fencing to obstruct access at the entrance to closed trails to fully clarify management intent. Even temporary 2 ft tall post and cord symbolic fences can communicate the importance of closures and effectively deter traffic (Figure 2) (Park *et al.* 2006). Taller plastic fencing (preferably in green or brown) is also easy to transport and install to discourage traffic on trails that prove more difficult to close. However, fencing is generally perceived as visually obtrusive and inappropriate in more primitive settings.

Placing rocks or woody debris that physically obstructs traffic beyond the beginning of closed trails may be ineffective if visitors are able to circumvent these by walking around them. This can result in new trampling and trails parallel to the "closed" trail – a significant problem in areas with sensitive or rare vegetation. In such areas it is better for hikers who ignore closures to remain on the "closed" tread than to create new treads on each side (Johnson *et al.* 1987). If the trail is in sloping terrain its closure may require the addition of soil to fill ruts and reestablish the original surface contour, and organic litter and vegetation to keep the soil from eroding. Finally, integrating site management work with temporary educational signs may be necessary to obtain a level of compliance that allows vegetative recovery. Also, consider signs to communicate the location of a preferred alternate route when visitors are seeking to reach a particular destination and their only visible access trail is closed.

Conclusions: Informal trail management actions should be implemented as part of an ongoing adaptive management program Experimentation will be necessary to refine site management procedures that are appropriate in each management zone or location. Some form of periodic monitoring is critical to program success. A 5-year interval could be sufficient for monitoring with quantitative procedures, but annual informal evaluations are needed to effectively guide the application of management actions.

Objective monitoring will be needed if any potentially controversial management actions may be needed (e.g., use restrictions or high fencing). In exceptionally high use areas with sensitive resources there is a good probability that such actions will be necessary. For example, a combination of signs and restoration work may be able to keep 95% of visitors on a designated trail but 5% of 2000 visitors/day is 100 visitors/day, a level of trampling that is sufficient to both create and maintain informal trails. Tall fencing or a regulatory sign that prohibits use of the closed trail and threatens fines may be necessary on trails that are particularly difficult to close. Such situations also indicate a need for further dialogue with trail users to discover their motives and a review of whether the formal trail system should be extended or modified.

Figure 2. Low symbolic post and rope fencing (left) and high fencing designed to physically obstruct access (right).

Regardless, periodic monitoring provides feedback for gauging the success of management interventions in keeping conditions within acceptable limits. A documented failure of one intervention can be used to justify the use of a more obtrusive or expensive intervention.

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