Assessing and Evaluating Recreational Trails on Public Lands

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Dissertation submitted to the faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of

Doctor of Philosophy
In
Geospatial and Environmental Analysis

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July 1st, 2009
Blacksburg, Virginia

Keywords: recreation ecology, impact assessment, trails, spatial analysis, Acadia National Park, George Washington Memorial Parkway

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ABSTRACT

This dissertation contains two journal articles; the first article (Chapter 2) evaluates the relative influences of use, managerial and environmental factors on trail width, from a survey of all formal trails in Acadia National Park, Maine, USA. Regression analyses of trail width data focus on increasing our understanding of the relationships among visitor use, environmental and managerial factors and trail width. In particular, regression modeling was used to evaluate the relative importance of factors that influence trail width along hiking trails. ANOVA analyses demonstrate differences in trail width based on trail surface type, and the presence or absence of trail borders. A novel approach of comparing intended widths to actual widths enabled us to look specifically at the avoidable and undesirable impacts associated with having a trail that is wider than intended. Informal trails (visitor created) represent a threat to the natural resources of protected natural areas around the globe. These trails can remove vegetation, displace wildlife, alter hydrology, alter habitat, spread invasive species, and fragment landscapes.

The second article (Chapter 3) examines informal and formal trails within Great Falls Park, VA, a sub-unit of the George Washington Memorial Parkway, managed by the U.S. National Park Service. This study sought to answer three specific questions: 1) Are the physical characteristics and topographic alignments of informal trails significantly different from formal trails, 2) Can landscape fragmentation metrics be used to summarize the relative impacts of formal and informal trail networks on a protected natural area?, and 3) What can we learn from examining the spatial distribution of the informal trails within protected natural areas? Statistical comparisons between formal and informal trails in this park indicate that informal trails have less sustainable topographic alignments than their formal counterparts. Spatial summaries of the lineal and areal extent and fragmentation associated with the trail networks by park management zones compare park management goals to the assessed attributes. Hotspot analyses highlight areas of high trail density within the park and findings provide insights regarding potential causes for development of dense informal trail networks.

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CHAPTER 1 INTRODUCTION

Protected natural areas are generally established and managed under a dual mandate to accommodate visitor access and recreation while protecting natural and cultural resources from degradation. In the United States, many of the most highly visited protected areas are managed by the National Park Service (NPS) and guided by laws directing park managers to balance visitor use and resource protection objectives, leaving resources “unimpaired” for “future use and enjoyment” (NPS 2001).

In seeking to avoid or minimize visitation-related impacts, the NPS has applied a wide range of strategies and tactics, including the development of recreation infrastructures such as 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 and Cole 1998; Marion and 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.

Recreation ecology is an applied field of science that seeks to understand and help manage visitor impacts on natural lands. This field of study helps to inform land managers about recreation-associated resource impacts and leads to the development of solutions that help balance visitor recreation and access with natural resource protection. By understanding the influence of use related (type, amount, behavior), environmental (vegetation type, topography), and managerial (site design and management, visitor education and regulation) factors, managers are better able to manipulate such factors to avoid and minimize visitation impacts while sustaining high quality recreation experiences. The research presented in this dissertation represents the cutting edge recreation ecology research, focused on two park problems: trail widening and informal trail development. Specifically, this research advances the field of recreation ecology in adopting the latest geographic information technology and analytical techniques through the use of GPS devices for data collection and GIS software for analysis of spatial phenomena.

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 (Marion and Leung 2004; Olive and Marion 2008). Formal trails are designed, constructed, and maintained to concentrate foot traffic and related impacts to minimize the areal extent of trampling damage and to avoid associated environmental impacts to vegetation and soils. When a trail is constructed, the surface vegetation and organic litter are removed, exposing underlying mineral soil that is shaped and compacted to drain water and provide a durable surface for visitor travel. Occasionally, further hardening, such as adding gravel, stepping stones, or boardwalks, is necessary to prevent degradation of the area from the intended uses. However, resource impacts associated with the use of formal trails can occur and such impacts do threaten or compromise natural area resource protection mandates. Examples include trailside vegetation impacts and trail widening, soil displacement, erosion, and muddiness.

A system of formal trails is the core component of park infrastructure that influences visitor travel patterns and 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 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. When dispersed or occurring on resistant substrates such as rock or grasses, there may be little measurable or permanent resource degradation associated with such activity. However, when off-trail hiking is substantial, or occurs on particularly fragile vegetation, resource degradation can occur rapidly through the creation/proliferation and degradation of informal (visitor-created) trail networks. Often referred to as "social trails," these unplanned networks can be extensive and may entail substantial resource impact to vegetation, soils, water resources, and wildlife.

This dissertation incorporates the findings of two related research studies, reported in a journal manuscript format, and included as Chapters 2 and 3. These papers represent cutting-edge research on trail-related resource impacts, including trail widening of formal trails and several impact attributes associated with the proliferation and degradation of informal trail networks. The first paper titled "The Influence of Use, Environmental and Managerial Factors on the Width of Recreational Trails" (Chapter 2) focuses on investigating the influence of factors that influence trail width. The study area for this research was the formal trail system on the main Mount Desert Island unit of Acadia National Park managed by the U.S. National Park Service (NPS).

Most of the existing body of research on formal trail impacts has focused on documenting vegetation and soil impacts along trails, and the influence of causal or non-causal factors (Marion 2006; Olive and Marion 2009). While understanding vegetation and soil impacts is paramount to designing and constructing sustainable trails, trail width also has important ecological and aesthetic implications. For example, a trail twice as wide as planned doubles the areal extent of intensive trampling-related impact. In addition to increasing the areal extent of impact, excessive trail widths can contribute to increased water run-off and erosion, altered hydrology, increased habitat fragmentation, and “day-lighting” of trail corridors that promotes altered plant composition by favoring shade-intolerant native and non-native species (Dale and Weaver 1974; Helgath, Intermountain et al. 1975; Cole 1978; Knight and Cole 1991; Tyser and Worley 1992; Marion 1994; Knight and Gutzwiller 1995; Kim, Lee et al. 2003; Leung 2007). The existing literature often only briefly mentions trail widening impacts and has included few analyses, mostly descriptive or limited to univariate relational analyses. Thus, existing literature holds little value for managers seeking insights for reducing this core form of trail impact and the aggregate extent of trail-related trampling damage.

This first dissertation paper provides a comprehensive review of the relevant literature, relational analyses of causal and non-causal factors that influence trail width, and a novel analytical approach that evaluates both actual trail widths and the difference between actual and “intended” widths. Field data collection was enhanced through the development of Geographic Information System (GIS) sampling techniques employing stratified point sampling with a random start. A research grade (Trimble GeoXT) Global Positioning System (GPS) was used to navigate to the sample points where trail measurements were assessed, eliminating the need to push a measuring wheel. Data collection was also streamlined through the development of paperless data collection practices utilizing data dictionaries and mobile spreadsheet applications on the Trimble GeoXT, which created spatial datasets that enabled the application of GIS analytical procedures.

The second dissertation paper titled “A Spatial Exploration of Informal Trail Networks within Great Falls Park, VA” (Chapter 3) focuses primarily on the resource impacts associated with the creation and use of informal trail networks. The study area was Great Falls Park, VA, a sub-unit of the George Washington Memorial Parkway, managed by the U.S. National Park Service. Protected area land managers and scientists have historically ignored these unplanned trail networks and their associated impacts. The numerous segments and duplicative and often dense intersecting alignments of such networks have challenged or thwarted prior assessment efforts. The net result has been very few studies and virtually no monitoring of informal trail impacts within protected natural areas, yet such impacts are common and substantial, particularly near popular attraction features. Furthermore, until recently, GPS devices have been insufficiently accurate to capture and adequately portray informal trail networks and few efforts have produced quantitative data for describing associated resource impacts, monitoring changes in their lineal or areal extent and tread conditions, evaluating management success in reducing associated impacts, or evaluating management standards of quality vital to carrying capacity planning and decision-making frameworks.

This study sought to address these deficiencies by pioneering the development of efficient quantitative assessment protocols that employed research-grade GPS devices and GIS analytical procedures. A variety of trail condition indicators were assessed from a census assessment of formal and informal trails within park boundaries. The formal trail data were collected for comparison purposes using point sampling techniques similar to those in the Acadia National Park study. Informal trails were known to be numerous and arrayed in complex networks throughout the park. Therefore, a rapid assessment technique was developed, refined, and applied to make census data collection feasible and allow for its continued application by NPS staff. The collection of accurate spatially-referenced informal trail data and use of GIS analytical procedures allowed the calculation of many quantitative indicators of informal trail impacts useful to both ecological and managerial interests.

Additionally, this study sought to answer three specific questions: 1) Are the physical characteristics and topographic alignments of informal trails significantly different from formal trails, 2) Can landscape fragmentation metrics be used to summarize the relative impacts of formal and informal trail networks on a protected natural area, and 3) What can we learn from examining the spatial distribution of the informal trails within protected natural areas? In order to address the first research question (comparing characteristics and topographic alignments of trails) we collected trail width in the field and extracted several other trail characteristics using a topographic model of the park in the GIS environment.

GIS techniques were used to further investigate the second research question; we examined the spatial distribution and interactions of the trail networks within the park and park management zones. These spatial analyses allowed for efficient and objective quantification of aggregate impacts associated with formal and informal trails and further contrasts by management zone. Borrowing from and building upon techniques implemented by Leung and Louie (2008) we calculated several landscape fragmentation metrics and discuss the relative levels of fragmentation within park management zones. The final research question was addressed by examining the density of lineal and areal informal trail impact within the park. A 10m grid was arrayed across the park and values for each cell in this grid were calculated as the density of trails within an 80m search radius from the center of the cell. Several iterations were run to examine the density of formal, informal and all trails within the park by both lineal and areal extent. Output raster (grid) data were classified and displayed to examine hot spots; critical examination of the informal trails within the hot spots supported a discussion of potential causes for informal trail creation, including visitor motives for leaving formal trails.

CHAPTER 2 THE INFLUENCE OF USE, ENVIRONMENTAL AND MANAGERIAL FACTORS ON THE WIDTH OF RECREATIONAL TRAILS

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Abstract: This paper evaluates the relative influences of use, managerial and environmental factors on trail width, from a survey of all formal trails in Acadia National Park, Maine, USA. Regression analyses of trail width data focus on increasing our understanding of the relationships among visitor use, environmental, and managerial factors and trail width. In particular, regression modeling was used to evaluate the relative importance of factors that influence trail width along hiking trails. ANOVA analyses demonstrate differences in trail width based on trail surface type, and the presence or absence of trail borders. A novel approach of comparing intended widths to actual widths enabled us to look specifically at the avoidable and undesirable impacts associated with having a trail that is wider than intended.

Keywords: Trail Width, Tread Width, Recreation Impact, Trail Impact, Tourism Impact

Introduction

A system of formal trails is a core and essential type of infrastructure in protected natural areas that facilitates visitor access and supports sustainable recreational opportunities and experiences. Protected area managers construct and maintain trails, condoning the requisite ecological disturbance and concentrate visitor traffic onto their durable substrates with the intention of preserving natural conditions in adjacent areas from visitor trampling. However, resource impacts associated with trail use can conflict with natural area resource protection mandates, thereby challenging land managers to implement visitor and resource management actions that avoid or minimize impacts. Formal trails should be routed, constructed, and maintained to concentrate foot traffic and related impacts to minimize the areal extent of trampling damage and to avoid associated environmental impacts to vegetation and soils. Though soil loss has been frequently investigated (Wilson and Seney 1994; Olive and Marion 2009), trail width has often been overlooked in relational analyses. Trail width has important ecological and aesthetic implications; a trail twice as wide as necessary doubles the areal extent of intensive trampling-related impact.

For example, at Great Smoky Mountain National Park in the United States, doubling trail width from one to two meters would increase total area of trampling disturbance by approximately 150 ha. In addition to increasing the areal extent of impact, excessive trail widths can contribute to increased water run-off and erosion, altered hydrology, increased habitat fragmentation, and “day-lighting” of trail corridors that promotes altered plant composition by favoring shade-intolerant native and non-native species (Dale and Weaver 1974; Helgath, Intermountain et al. 1975; Cole 1978; Knight and Cole 1991; Tyser and Worley 1992; Marion 1994; Knight and Gutzwiller 1995; Kim, Lee et al. 2003; Leung and Louie 2008).

Guidance for construction and maintenance of trails often specifies trail characteristics such as recommended trail corridor clearing dimensions and trail width. Upon reflection of differing nomenclature in the literature, we define *trail corridor width* as the gap in vegetation trimmed by trail maintainers to allow easy passage of the intended trail users. *Trail width* is defined as the portion of the trail corridor that directly supports the majority of recreational traffic. As depicted in Figure 2.1, this includes portions of the trail that are barren substrate and trampled vegetation or organic litter when present. *Tread width* is defined as the core or most heavily trafficked portion of a trail, generally only the exposed barren substrate and/or the flatter bottom portion of incised trails. Tread width is often narrower and more intensively degraded than trail width, though trail width can be equivalent to tread width.

As previously noted, formal trails constitute a recreation infrastructure component designed, constructed, and maintained to protect natural areas by focusing traffic on a narrow band of durable substrates. Trail construction and maintenance-related resource manipulations should not be assessed as recreational “impact” since they are essential to the provision of a trail network. For example, the United States Forest Service provides specifications for trail width and trail corridor vegetation trimming that vary by type of use, trail class, and land designation (Hesselbarth, Vachowski et al. 2007). Equestrian use dictates a wider trail with broader and taller vegetation clearing limits than a trail intended solely for pedestrian or cycling uses. An important issue overlooked in scientific and monitoring trail condition assessments is the need to account for the maintained trail width when assessing trail width as an indicator of visitor impact. No previous studies appear to have done this, possibly because land managers often fail to specify intended widths or to maintain trails at those widths. We suggest that when possible, trail impact assessments should also employ a trail width difference measure, defined as the *difference* between intended and actual trail width.

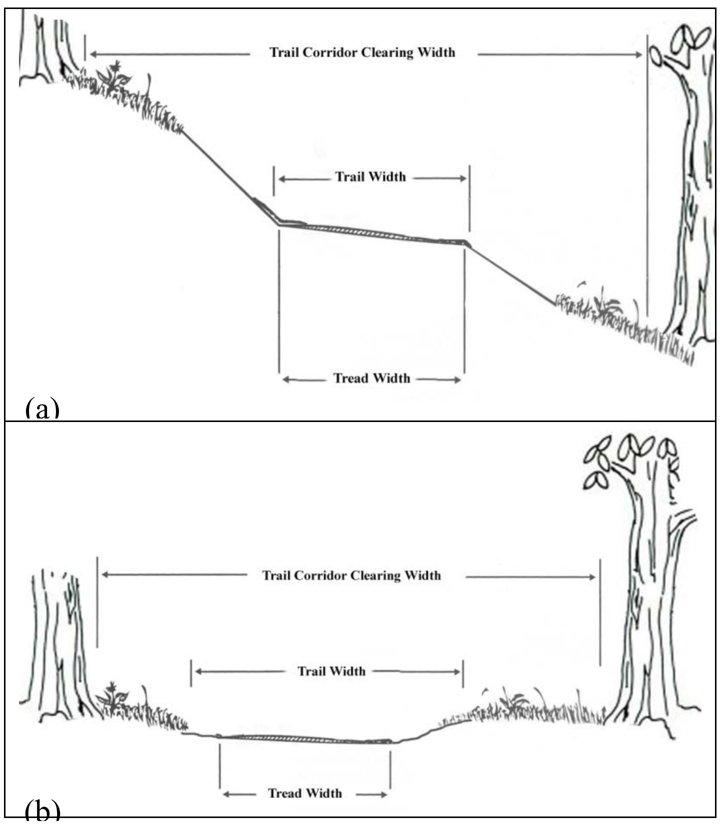

Figure 2.1 Illustrations of trail corridor, trail, and tread width for (a) constructed side-hill trails (aligned close to the contour), and (b) non-constructed fall-aligned trails (aligned perpendicular to the contour).

This study seeks to investigate the relationships and influences of a wide range of use-related, environmental and managerial factors on trail width at Acadia National Park (ACAD). Data are analyzed from a comprehensive field survey of the park's formal trail system, completed to support National Park Service (NPS) planning and management decision-making. In addition to a more holistic investigation of variables that influence trail width, this study provides a unique opportunity to investigate differences between intended and actual trail width. ACAD managers were able to provide data on intended or design width for each trail segment in their inventory; by calculating the difference between intended and actual width we investigated relationships between various influential factors and “width difference.” Past studies have frequently used actual width as the dependent variable. This study recognizes that trails are not designed or maintained to one universal width due to differences in use types and amounts, terrain and environmental factors, varied management objectives, and construction materials and methods. By examining width difference, we are able to evaluate when a trail segment is wider, narrower, or equal to the intended width.

Literature Review

Trail width investigations have employed differing methods for assessing trail width: some assessed trail and tread widths as defined here, others applied variations or failed to clarify what they measured (Bayfield 1973; Lance, Baugh et al. 1989; Hawes, Candy et al. 2006; Törn, Tolvanen et al. 2009). These differences and omissions of assessment methods have produced data that are often not comparable between studies. Recent studies (Marion and Leung 2001; Marion and Hockett 2008; Olive and Marion 2009) have adopted a more standardized and objective method for defining and assessing trail boundaries based on visually obvious trampling-related changes in ground vegetation and organic litter characteristics.

Many studies have cited increases in trail width as a degradation of the overall condition of a protected natural area (Helgath, Intermountain et al. 1975; Lance, Baugh et al. 1989; Cole 1991; Kim, Lee et al. 2003). Leung and Marion (1999) conducted a problem assessment survey of the 528 km formal trail network in Great Smoky Mountains National Park; the study cataloged segments of trail with excessive trail widths of 91-183 cm (150 segments, 3058 m), and exceeding 183 cm (26 segments, 531 m). Excessive trail width is a general concern for land managers of protected natural areas because it represents intensive trampling and environmental degradation that is *avoidable*.

Understanding how various use-related, environmental, and managerial factors cause, facilitate, or inhibit trail widening can help managers make informed decisions in selecting effective strategies to prevent or reduce this form of trail impact. Several descriptive and experimental studies have sought to gain an understanding of the interrelationships between trail width and different types and amounts of use, and user behavior. While initial trail construction establishes an intended trail width, unless actively maintained, use-related, environmental, and managerial factors largely influence trail width in later years. One would expect trail width to vary by type of use, with bicycles creating the narrowest trails, and wider trails required to support hikers, horses, and ATV's corresponding to their greater widths. Significant use-type differences in mean trail widths from a study of 126 km of backcountry trails in a large United States National Park support this expectation: bike (61cm), hiker (82cm), horse (208), and ATV (267cm) (Marion 2006).

Investigations on the influence of amount of use on tread width have provided mixed results. Several studies have found strong correlations between increasing trail width and amount of use (Bayfield 1973; Dale and Weaver 1974; Weaver and Dale 1978; Coleman 1981; Boucher, Aviles et al. 1991; Farrell and Marion 2002; Nepal and Way 2007) while several other studies found no or weak correlations (More 1980; Marion 1994; Bjorkman 1996). These studies reveal that initial low levels of traffic are sufficient to remove vegetation and litter cover, establishing a narrow trail tread that expands little in width unless large numbers of visitors engage in tread widening behaviors.

As noted by Cole (1991), the primary agent of trail widening is trampling, rather than water which is the agent of change for the two other primary forms of trail degradation, soil erosion and muddiness. We additionally note that *where* trail users trample is a function of their behavior, though an array of environmental and managerial factors influence behavior. We identify six general behaviors that contribute to trail widening: 1) passing other trail users, 2) side-by-side travel, 3) avoidance of tread problems (e.g., muddiness, erosion, roughness), 4) inability to remain on the intended tread due to poorly marked trails or ambiguous tread borders, 5) roaming associated with picking the easiest route when traversing steep grades, and 6) attraction and avoidance behaviors (e.g., gaining a view or staying away from a drop-off). We further hypothesize that the number of trail users engaging in these behaviors increases with increasing amounts of trail use, particularly for behavior one.

Environmental factors have shown strong influence on trail width because of their influence on human behavior. Bayfield's (1971, 1973) investigations of trail widths in the Cairngorm Mountains of Scotland, revealed that the steeper trailside terrain of contour-aligned trails effectively limits trail width, while trailside topography does not limit the expansion of trails that more directly ascend slopes, which were substantially wider. Fall-aligned trails also grew wider with increasing grade, likely due to a tendency for hikers to wander laterally on steep trails to select the easiest route. Trail widths increased sharply with increasing soil wetness, presumably due to hikers seeking to circumvent muddy treads. High micro-topographic variance (surface roughness or stoniness) of trailside areas acted to constrict trail width, though this factor was less influential than soil wetness. A study by (Pounder 1985) found that stoniness on trail treads encouraged the lateral spread of traffic and increased trail width.

Bayfield also placed an array of wire pins across trail corridors to assess trampling patterns, documenting the extent of trail widening and off-trail hiking patterns in various environmental settings. Results revealed that woody forest vegetation more effectively constricts trail traffic than open meadow vegetation, where off-trail hiking and trail widening behaviors were more frequent corroborated by (Bright 1986). In summary, trail conditions, including tread roughness and trailside barriers to travel (woody vegetation and boulders), are important constraints to lateral trampling dispersion.

Multiple regression analyses by Marion (1994) investigated the relative influence of twelve variables on trail width in Great Smoky Mountains National Park. This work confirmed a number of Bayfield's (1971, 1973) findings: 1) wet soil was the most significant predictor of excessive trail width, 2) a strong positive correlation between trail width and trail grade indicates steep alignments exacerbate trail widening, and 3) trails in mid-slope positions were significantly narrower, likely due to side-hill alignments where steep side-slopes inhibit trail widening. A measure of trail root exposure was also included in the model with a positive correlation, suggesting that trail users trying to circumvent exposed tree roots contribute to trail widening. Calais and Kirkpatrick (1986) investigated trail widening in the alpine wetlands of the Tasmanian highlands, finding that trail muddiness caused hikers to expand trail width and create new parallel treads. Collectively, these studies reveal that any tread condition that impedes travel such as severe erosion, muddiness, tread roughness, or steep grades, will exacerbate behaviors that widen or create new parallel treads, particularly when trailside conditions offer more favorable footing.

Few studies have directly examined the influence of site and visitor management, two types of managerial actions that have potential for modifying use-related and environmental factors (Leung and Marion 1996; Newsome, Moore et al. 2001). Perhaps the most important factor governing the long-term sustainability of a trail is the location and design of its alignment (IMBA 2004; Marion and Leung 2004; IMBA 2007). This literature review suggests that managers can limit the expansion of trail widths by employing side-hill designs and avoiding flat terrain, wet soils, and steep trail grades. Other options include routing trails through dense vegetation or settings where the constructed tread is more favorable than trailside terrain, such as rocky or wet areas (Parker 2004). Other site management actions include a maintenance program that sustains a tread of sufficient width to accommodate intended uses and that facilitates traffic better than trailside areas (e.g., more smooth, dry, and unobstructed). Trails can be routed between natural features that periodically narrow traffic or such features can be strategically added, such as large logs or rocks placed at intervals or continuously as trail borders. (Doucette and Kimball 1990)) found that scree walls erected as trail borders reduced mean tread width from 3.6 to 2.1 meters and an observational study (Park et al., 2008) found that low symbolic fencing reduced off-trail traffic from 74% to 1.2%. Finally, the width of vegetation trimming can exert a strong influence to control trail widths (Hesselbarth, Vachowski et al. 2007; Steinholtz and Vachowski 2007).

Visitor management actions include educational or regulatory actions that modify human behavior. Direct actions include prohibiting certain uses or activities, restricting types of uses to trails best able to sustain their use, or prohibiting use during sensitive seasons (e.g., wet periods) (Cole, Petersen et al. 1987). Restricting off-trail hiking would likely not effectively limit trail widths and reducing the amount of use would likely be less effective than many other site management actions reviewed here (Cole 1991). Indirect actions include educational programs designed to alter behavior by informing visitors of the impacts associated with certain behaviors and encouraging adoption of low-impact practices. For example, the national *Leave No Trace* program encourages visitors to “walk single file in the middle of the trail, even when wet or muddy” (www.LNT.org). Numerous studies have shown such educational practices to alter behaviors effectively, though few have investigated subsequent improvements in resource conditions (Marion and Reid 2007; Park 2008).

Study Area

The study area for this survey of formal trail conditions was the Mount Desert Island (MDI) portion of Acadia National Park, located on the Atlantic coast of Maine, USA (Figure 2.2). This 27,900 ha glaciated rocky island includes 13,300 ha in park ownership (47.5 % of the island). Park visitation was approximately 2.2 million visitors in 2007 (NPS 2009) the busiest tourist season is in the 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 2.2). This study was restricted to assessing the 183 km of formal hiking trails for the purpose of establishing and monitoring standards of environmental quality.

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 glaciation 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 (Barter, Brown et al. 2001 Draft).

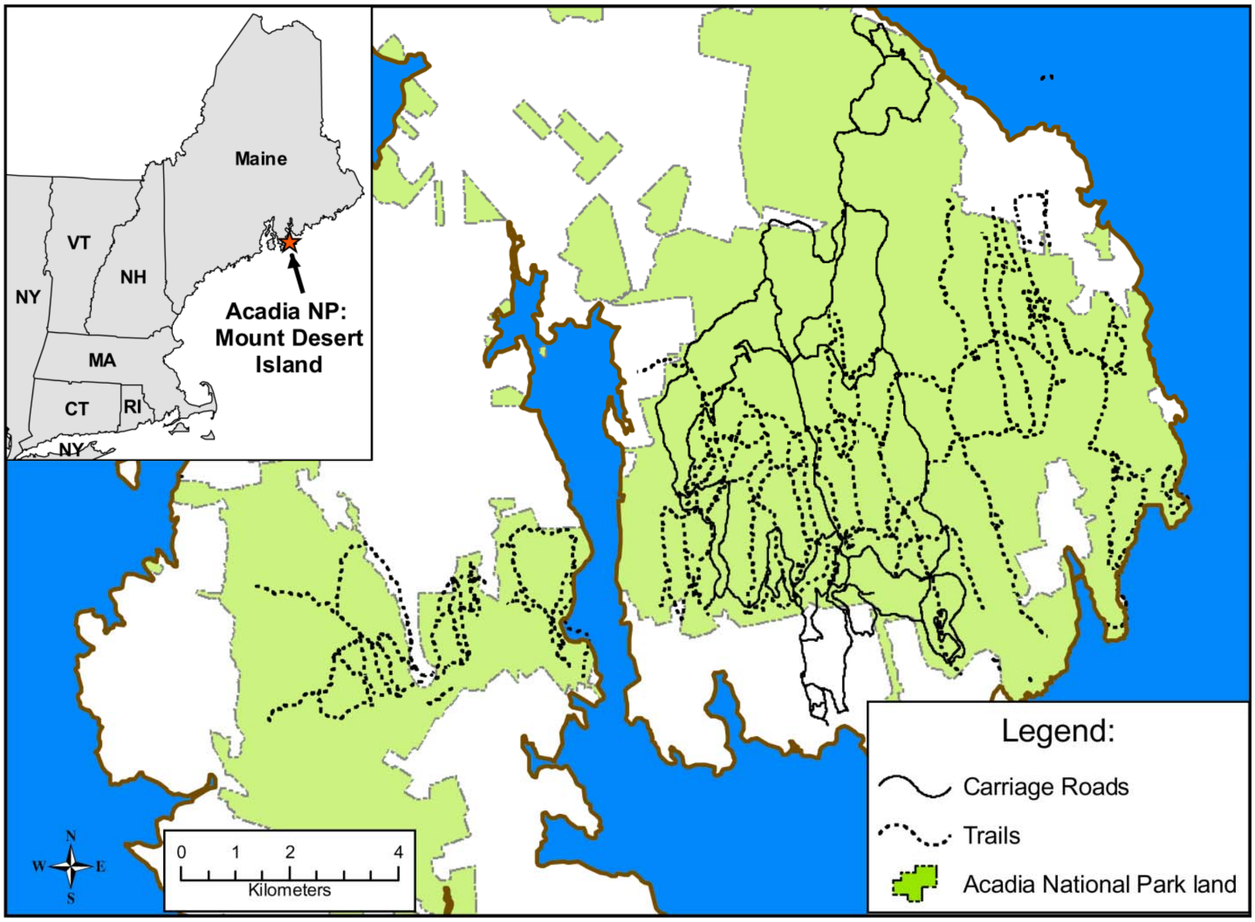

Figure 2.2 Acadia National Park, Mount Desert Island trails and carriage roads. The island has over 183 km of hiking trails within the park boundaries.

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.

Sampling and Measurement Procedures

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 (1999), 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 152.4 meter (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 152.4 meter interval. 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 was 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. 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.

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. The distance between these disturbance-associated boundaries was measured as trail width. Trail width was coded as "not applicable" in instances when sample points fell on barren non-vegetated bedrock.

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 and Marion 1996). The TSA of a contour-aligned trail would equal 90^{o} while a "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%.

The rugosity, or roughness, of the trail surface was calculated from measurements taken to compute cross sectional area soil loss estimates (not reported in this paper) (Cole 1983; Marion and Hockett 2008). 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 9.14 cm for narrower trails and 30.48 cm for wider trails. Rugosity was calculated as the standard deviation of these vertical measurements at each transect. This value is a linear analog of the rugosity values that Bayfield (1971, 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.

Knowledgeable NPS and trail steward staff, in consultation with trail counter and trailhead/trail intersection use counts, 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.

Analysis

Data were assembled in the attribute table of the transect data shapefile in ArcMap 9.3, 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 and width difference. Regression analyses used general linear models and backward step-wise selection methods to isolate variables that significantly influence trail width or width difference. Categorical variables were represented with dummy variable coding to evaluate the relative influence of each category. An overall model was developed, along with models that grouped variables into use-related, environmental, and managerial categories. ANOVA tests compared the values of trail width and width differences against several independent variables.

Results

Mean trail width for MDI trails was 104 cm, while mean trail width difference was 22 cm, indicating that trails are generally 21% wider than intended by park management (Table 2.1). Comparison of mean trail width and mean width difference by tread substrate class reveal significant differences between tread substrate classes (Table 2.1). Natural-surfaced trails have a mean trail width of 105 cm and the greatest mean width difference (28 cm). Graveled trails have the widest average trail width (126 cm) but are close to their intended width. Boardwalks and bridges are expensive to construct, require ongoing maintenance, and represent increased liability to land managers; however, trail alignments that cross wet areas, water features, and extreme terrain often necessitate the use of these features. A variety of trail features fit this category, including simple bog planking, corduroy, puncheons, constructed boardwalks, and bridges. Boardwalks and bridges are not only narrowest (50 cm), but are also half as narrow as their segment's intended width (mean width difference = -49 cm). Native stonework is commonly used on steeper fall-aligned trails to construct staircases and walkways, providing stable footing in steep and rough terrain. Trail segments with manmade stonework are also relatively narrow (71 cm) and are generally less wide than intended.

A one-way analysis of variance (ANOVA) test revealed that trail width varies significantly by substrate class. For trail width difference, the test reveals three unique groupings of substrates; natural surface and boardwalk/bridge substrates are significantly different from the others, while graveled and stonework trail segments comprise the third unique grouping.

In summary, natural-surfaced trails are substantially wider than intended and have a significantly larger mean width difference than the other substrate classes. Graveled trails are the widest, followed by natural-surfaced, stonework, and boardwalk/bridge segments.

Table 2.1 Trail width and trail width difference as influenced by tread substrate.

Trail Substrate	Trail Width[1] (cm)	Trail Width Difference[1] (cm)
Natural Surface *(n=810)*	105^a (47)	28^a (51)
Graveled *(n=120)*	126^b (48)	5^b (48)
Boardwalk/Bridge *(n=20)*	50^c (24)	-49^c (27)
Stonework *(n=48)*	71^d (24)	-9.3^b (28)
Total *(n=998)*	104 (48)	22 (52)

[1] Mean and standard deviation values. Groupings based on Tukey's Student B Groups; values with the same letter are not significantly different (alpha=0.05)

The influence of trail borders on trail width was investigated through ANOVA tests of trail width and width difference grouped by the number of borders present (Table 2.2). While actual trail width declines between groups with zero, one, or two borders, these differences are not statistically significant. In contrast, trail width difference values decline more markedly with increasing numbers of trail borders and the trails with no borders are significantly wider than intended (25 cm) in comparison to trails with one or two borders, which are not significantly different from one another (mean width differences of 7 and -5 cm, respectively).

Table 2.2 Trail width and trail width difference as influenced by number of trail borders.

Trail Borders (#)	Trail Width[1] (cm)	Trail Width Difference[1] (cm)
0 *(n=847)*	106^a (49)	25^a (54)
1 *(n=110)*	94^a (38)	7^b (36)
2 *(n=41)*	92^a (38)	-5^b (35)
Total *(n=998)*	104 (48)	22 (52)

[1] Mean and standard deviation values. Groupings based on Tukey's Student B. Groups with the same letter are not significantly different (alpha=0.05)

The subset of sample points for natural-surfaced trails (n=810) were further investigated through a series of regression analyses to evaluate the individual and collective influence of use, managerial, and environmental factors on trail width (Table 2.3) and trail width difference (Table 2.4). For trail width data, a natural log transformation was required to normalize data;

consequently, the regression coefficients are unstandardized natural log values. Trail width difference values did not require a transformation so regression coefficients are unstandardized values.

Four models were constructed for each dependent variable: 1) a use-related model that includes the categorical use level variable, 2) an environmental variable model with landform grade and landform position, 3) a managerial model with trail grade, TSA, slope ratio, rugosity, and borders, and 4) an integrated model with all variables input and utilizing backwards step-wise selection to remove insignificant factors.

Table 2.3 Influence of use-related, environmental, and managerial variables on trail width for natural-surfaced trails.

Variables	**Regression Models**[1]			
	(1)	(2)	(3)	(4)
Use-Related				
Use Level:	(0.000)[2]			(0.000)
High	(0.012) 0.171[3]			(0.011) 0.225
Medium	0			0
Low	(0.000) -0.269			(0.000) -0.237
Environmental				
Landform Grade		(0.279) 0.001		
Landform Position:		(0.000)		
Fall-line		(0.000) 0.124		
Sidehill		0		
Managerial				
Trail Grade			(0.789) 0.001	
TSA			(0.507) 0.000	
Slope Ratio			(0.756) 0.030	
Rugosity			(0.000) 0.139	(0.000) 0.115
Borders			(0.099) -0.101	(0.059) -0.109
Adjusted R^2	0.102	0.017	0.074	0.162
Estimated Effect Size	Small-Medium	Small	Small-Medium	Medium

[1] Regressions run with General Linear Model using log transformation of trail width as the dependent variable.
[2] Two-tailed t-test significance
[3] Unstandardized *ln(TrailWidth)* coefficients, in centimeters

The use-related model (Table 2.3, #1) indicates that use level is a significant influence on trail width; using medium use level as the reference category for the dummy variable coding, the high and low use trail width values are significantly different ($p < 0.05$) from medium. The beta coefficient for high use trail is positive (0.171) indicating an increase in trail width from medium use, while the beta coefficient for low use trails is negative (-0.269), indicating a decrease in trail width from medium use.

Within the environmental model (#2), landform grade is not a significant influence on trail width but landform position is ($p < .001$). The positive coefficient for fall-line trails reveals that these alignments are wider than side-hill trails and this difference is statistically significant ($p < .001$).

The third model contains managerial variables, factors manipulated through trail design and maintenance. Of the five variables in this model, only rugosity significantly influences trail width ($p < .001$). Rugosity has a positive coefficient, indicating that trail width increases with increasing rugosity (trail roughness).

The final model (#4) begins with inclusion of all variables and utilizes backwards step-wise selection to remove insignificant variables. However, only two of the eight variables are significant, use level ($p < .001$) and rugosity ($p < .001$). In summary, regression modeling using actual trail width values reveals that trail width increases with increasing level of trail use and rugosity and decreases with the addition of trail borders.

Adjusted R-squared values for trail width regression models ranges from 0.017 for the environmental model to 0.162 for the overall model. Cohen's *A Power Primer* (Cohen 1992) is used to estimate effect sizes based on these adjusted R-squared 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 range from small for the environmental model to medium for the overall model (Table 2.3).

A second set of models mirrors the first set, substituting width difference as the dependent variable, and employing identical procedures . The use-related model (Table 2.4, #1) reveals that use level also significantly influences trail width difference ($p < 0.001$). As expected, the positive coefficient for high use (20.2) and negative coefficient for low use (-8.9) indicate that trail width difference values increase with level of trail use.

The environmental model (#2) reveals no influence from landform grade ($p = .748$), but landform position is significant ($p < 0.001$). The positive coefficient for fall line trails indicates that trail width difference increases with fall line alignments relative to sidehill alignments.

The managerial model (#3) includes two significant variables, rugosity ($p < 0.001$) and borders ($p < 0.031$). The positive coefficient for rugosity indicates that as tread roughness increases, trail width difference also increases. The negative coefficient for trail borders indicates that as the number of borders increases, trail width difference decreases.

The final model (#4) includes all variables initially and utilizes backwards step-wise selection to remove insignificant variables. Five of the eight variables are statistically significant and included in the final model: use level, landform grade, trail grade, rugosity, and borders. Relationships as previously described are found for use level, and rugosity. Borders ($p< 0.031$) have a negative coefficient indicating that as the number of borders increase, the width difference decreases. Landform grade ($p < 0.001$) has a negative coefficient, indicating that trail width difference values decrease with increasing landform grade. Trail grade ($p < 0.043$) has a positive coefficient, indicating that trail width difference values increase with increasing grade.

Adjusted R-squared for width difference regression models ranges from 0.015 for the environmental model to 0.116 for the overall model. According to Cohen's (1992) effect size indices, the effect size estimates range from small for the environmental model to medium for the overall model.

Additional analyses were conducted to assess the influence of landform grade, the slope of the dominant fall-line, and landform position. Landform position is a binary variable that describes the orientation of the trail to the fall line, as either side-hill (parallel to the contour) or fall-line (perpendicular to the contour). The influence of these attributes on mean trail width and mean width difference is shown in Figure 2.3. Landform grade was categorized as shallow (0-10%), moderate (11-30%), steep (31-60%) and extremely steep (>60%).

Table 2.4 Influence of use-related, environmental, and managerial variables on trail width difference for natural-surfaced trails.

Variables	Regression Models[1]			
	(1)	(2)	(3)	(4)
Use-Related				
Use Level:	(0.000)[2]			(0.001) 0.030
High	(0.021) 20.2[3]			(0.044) 21.723
Medium	0			0
Low	(0.070) -8.9			(0.048) -11.542
Environmental				
Landform Grade		(0.748) 0.032[3]		(0.001) -0.433
Landform Position:		(0.000) 0.016		
Fall-line		14.0 (0.000)		
Sidehill		0		
Managerial				
Trail Grade			(0.995) 0.002	(0.043) 0.532
TSA			(0.200) -0.156	
Slope Ratio			(0.956) -0.641	
Rugosity			(0.000) 16.937	(0.000) 14.591
Borders			(0.031) -153537	(0.031) -15.252
Adjusted R^2	0.017	0.015	0.082	0.116
Estimated Effect Size	Small	Small	Small-Medium	Medium

[1] Regressions run with General Linear Model using trail width difference as the dependent variable.
[2] Two-tailed t-test significance.
[3] Unstandardized *Width Difference* coefficients, in centimeters.

Mean trail width for side-hill trails decreases as landform grade increases (from 104 cm in 0-10% grades to 92 cm in >60% grades). When looking at fall-line oriented trails we see an increase in mean trail width with increasing landform grades (from 104 cm in 0-10% grades to

124 cm in 31-60% grades). Similar trends are evident in the trail width difference data; where width difference is similar between fall line and side-hill trails at low landform grades. Side-hill trails are closer to their intended widths as landform grade increases but fall-line trails are substantially wider than intended at higher landform grades (e.g., 26 cm for 0-10% landform grades to 51 cm for 31-60% grades).

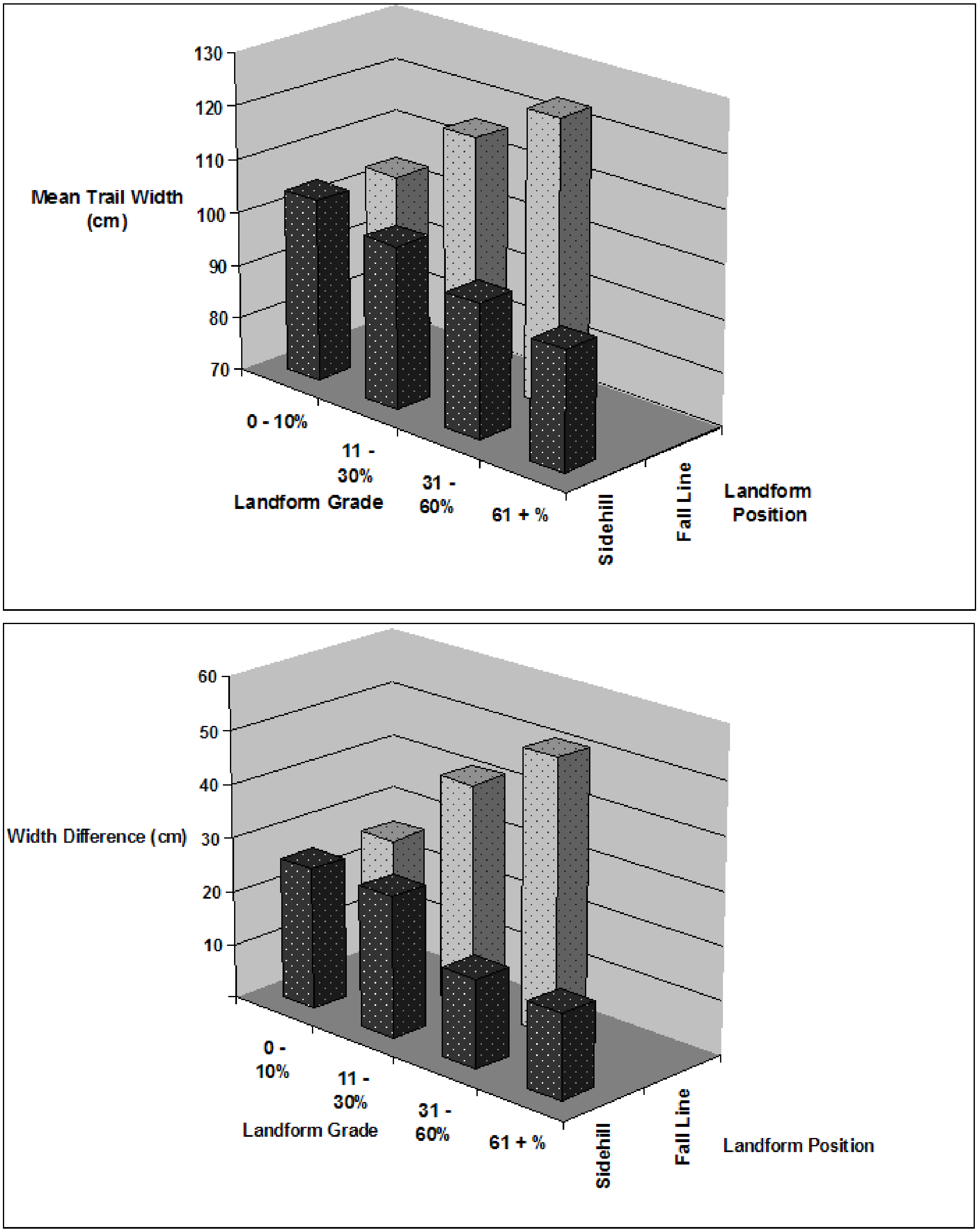

Figure 2.3 Trail width and trail width difference as influenced by landform grade and landform position. Mean values shown; classifications with n<10 omitted.

Discussion

Research presented here focused on developing an understanding of the use, managerial, and environmental factors that influence trail width on the formal trail network of Acadia National Park. The application of a paperless GIS/GPS-based trail sampling protocol produced a representative systematic sample of 1117 trail transects across the 183 km MDI trail system. The methods provide an efficient framework for the collection of spatially referenced data that enable GIS analyses and presentation of findings and that avoided problems associated with traditional measuring-wheel assessment techniques. Trail width definitions and assessment procedures were also found to be appropriate and efficiently applied across a wide range of conditions. These protocols and nomenclature are recommended for application in future monitoring or research surveys to improve data comparability.

This research took a unique approach by investigating the difference between manager's intended (design) trail widths and actual trail widths. Width differences greater than zero are representative of avoidable impact; managers have specified a desired width and visitors trailside trampling behaviors have created a wider corridor. Conversely, width difference less than zero represent segments where visitors have concentrated their trampling to a narrower than intended path. The width difference approach yielded a new trail width measure that allows a more explicit determination of avoidable or unacceptable impact. Its subsequent use in relational analyses provided greater insights into understanding the influence of factors on trail width.

Research findings show significant differences in trail width and width difference based on trail substrate class and the number of trail borders present. Further regression analyses investigated the relationships of use, environmental, and managerial factors on trail width and width difference for natural surfaced trails.

Trail Substrate

Analysis of trail width by trail substrate class reveals significant differences in trail width among all classes, and three unique groupings with respect to width difference values (Table 2.1). Graveled trails are widest with a mean trail width of 126cm (n=120). In order to accommodate higher levels and volumes of traffic, land managers will often apply gravel to harden trails in more developed park settings. Width difference values for gravel trails show that despite being the widest class of trails, they are closest to their intended width (mean width difference of 5cm) likely because the gravel provides a more durable and easy substrate for walking, in comparison to natural surfaces just off-trail.

Mean trail width for artificial tread surfaces is the smallest of our groups at 50cm (n=20). Material and construction costs restrict their designed width. Width difference values are significantly narrower than any other class (-49 cm), likely because their surfaces support traffic better than alternative natural surfaces and they are located within longer trail segments that have wider intended widths.

Mean trail width for stonework treads is 71cm (n=48), with a mean width difference of -9.3cm, suggesting that this type of surface also supports traffic better than adjacent natural surfaces and/or that they are located within longer trail segments with wider intended widths.

The natural surface class of trails is the second widest group of trails with a mean trail width of 105cm (n=810). More importantly, this class of trails has the largest mean width difference (28cm), indicating that trail widths are much wider than intended possibly due to difficulties in defining a visually obvious intended tread, or to the challenges of constructing and maintaining natural-surfaced treads in better condition than adjacent trailside terrain. These empirical data collectively reveal artificial substrates (gravel, wood, stonework) provide an inviting hardened tread that visitors will stay on, thus limiting trail widening and trampling-related resource degradation. These artificial substrates also prevent the development of muddy or wet trail sections and limit erosion. A challenge for managers is determining where such successful but artificial actions are appropriate. An earlier study at this park found that visitors approved of such trail hardening options in accessible areas near popular attraction features, but expressed little or no support for their use in more remote park settings (Cahill, Marion et al. 2008).

Borders

Trail widths decline with increasing numbers of trail borders (0-2) but differences are not statistically significant (Table 2.2). However, trail width difference values decline more substantially with increasing numbers of trail borders, and differences are statistically significant. Trails with one or two borders have significantly smaller mean width differences (7 cm and -5 cm, respectively) than trails with no borders (25 cm). Trail borders provide visitors with unambiguous visual guidance clarifying what constitutes the trail tread, a largely symbolic physical barrier, and an implied management message to “stay on the trail.” Trail borders may also be used to elevate and/or retain tread substrates. As with use of artificial substrates, trail borders are generally used in more developed park settings, or in remote settings when needed to protect sensitive resources.

Relational Analyses

While applying artificial trail substrates or trail borders can help to minimize trail widths, these treatments may be impractical in remote or less developed settings of protected areas due to their higher cost or because visitors may view them as artificial solutions inconsistent with natural area conditions, aesthetics, and values. Thus, natural surfaced trails maintained through limited use of native materials are an integral part of protected area management. Therefore, regression analyses and modeling using only natural surface trail data examined how use-related, environmental, and managerial factors influence trail width (Table 2.3: models 1, 2, 3), width difference (Table 2.3: Models 1, 2, 3), and integrative models for each dependent variable (Tables 2.3 and 2.4: Model 4).

Use-Related Factors

While the park's carriage roads are multi-use, the trail system is limited to hikers because of the rocky terrain and steep grades common in much of the park. Our analyses of use-related variables were limited to amount of use, provided by NPS staff as categorical data (high, medium, and low use levels). The trail width model (Table 2.3, Model 1) indicates that trail width increases significantly with increasing levels of trail use ($p < 0.001$). However, examination of the unstandardized beta coefficients reveals a much smaller increase in trail widths from medium use (the reference category) to high use (0.17), than from low use to medium use (0.27). This is consistent with the common research finding of an asymptotic relationship between amount of use and many forms of resource degradation (Weaver and Dale 1978). A majority of degradation occurs with initial and lower levels of traffic, with per capita impact diminishing markedly as use levels increase.

A width difference model for amount of use (Table 2.4, Model 1) shows that actual trail widths grow increasingly and significantly wider, in comparison to intended trails widths ($p<0.001$), as use levels increase. However, for trail width difference, the unstandardized beta coefficients output by the model reveal a significantly larger width difference value for the medium to high use level comparison (20.2), than for the low to medium use level comparison (8.9). Given the trail width findings just reported, we attribute these width difference findings to unrealistic management expectations for intended trail widths that are insufficient to accommodate the extremely heavy use that some park trails experience.

Environmental Factors

The environmental models (Tables 2.3 and 2.4: Model 2) includes variables related to the topography upon which the trail is located: landform grade, a scalar variable, and landform position, a categorical variable. Only landform position was found to significantly influence trail width and width difference (both $p<0.001$) (Tables 2.3 and 2.4, Model 2). The positive beta coefficients for fall-aligned trails reveal these alignments have wider trail widths than sidehill trails and sidehill trails are generally more narrow than intended. These findings are consistent with those reported in several other studies (Bayfield 1971; Bayfield 1973; Marion 1994).

Trails designed with sidehill alignments (Figure 2.1a) are preferred over fall-aligned trails (Figure 2.1b) for numerous resource protection reasons. Sidehill trails provide a hydrological advantage over fall-aligned trails because water is travelling down the dominant landform grade at an angle to the trail; surface runoff that encounters the trail can easily move across outsloped treads or be channeled off the tread with drainage features. Fall-aligned trails run parallel to the water flow, so runoff is captured and channeled directly down a trail, eroding tread substrates and creating ruts that capture and transport additional water (Olive and Marion 2009).

Our environmental models for trail width and width difference indicate that in addition to hydrological reasons for favoring sidehill alignments, these trails are narrower and have smaller width differences than their fall-aligned counterparts. We hypothesize that trail widening behaviors are substantially discouraged by steeper side-slopes above and below sidehill trail alignments. Hikers find it easier to travel along the flatter bench cut from the sloping terrain, than to walk on the steeper trailside terrain.

Managerial Factors

The third regression model evaluated the influence of variables directly managed through construction and maintenance actions. Of the five variables included in this model, only rugosity significantly influences both trail width and width difference (both $p<0.001$) (Tables 2.3 and 2.4, Model 3). Rugosity's positive beta coefficients indicate that trail widths and width difference values increase with increasing rugosity. These findings are consistent with Bayfield's studies (1973, 1971), suggesting that trail roughness can cause hikers to widen trails by seeking out smoother trailside hiking surfaces. This agreement in findings also supports our substitution of rugosity as an alternative measure for Bayfield's surface roughness variable.

We further hypothesize that trail users instinctively travel along the "path" of least resistance. Therefore, managers can contain the lateral spread of traffic along trails by designing, constructing, and maintaining a tread surface that makes it the clear and easy choice for travel. This does not mean that all trails must be managed for smooth featureless treads, only that tread surfaces should be more inviting of traffic than the trailside environment. 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.

The influence of trail borders was also found to be a significant predictor of tread width difference ($p<0.031$) (Table 2.4, Model 3). A negative beta coefficient indicates that as the number of borders increases, trails become narrower than their intended widths, a trend also found in the ANOVA test (Table 2.2). Trail borders are likely to be most effective in areas where trail widening is unhindered by topography or vegetation and trail boundaries are ambiguous. While trail borders of rock or wood are artificial in appearance, they provide highly effective visual borders without the height, like fencing, necessary to offer a physical obstacle. Taylor (Taylor 1981; Olive and Marion 2009) found that simple rock scree walls contributed in preventing 90% of hikers from entering rare plant habitat along a trail on Mt. Washington.

<u>Overall</u>

Two overall models, trail width and width difference (Tables 2.3 and 2.4, Model 4) provide insights into the relative influence of use-related, environmental and managerial factors considered collectively. Stepwise backwards selection eliminates insignificant ($p>0.05$) variables, leaving two variables that significantly influence trail width, and five that significantly influence width difference.

Within the trail width overall model (Table 2.3, Model 4), only use level and rugosity are found to significantly influence trail width. Landform position, a significant influence in the Model 2, was omitted from the Model 4, indicating a lower relative influence. The beta coefficients for use level and rugosity suggest the same relationships exist as previously described in Models 1 and 3. Adjusted R-squared for Model 4 indicates that use level and rugosity account for approximately sixteen percent of the variation in trail width; however Cohen' (1992) effect size estimation procedure yields our largest estimated effect size (medium) for this model.

The width difference overall model (Table 2.4, Model 4) includes five significant variables: use level, landform grade, trail grade, rugosity, and borders. Use level, rugosity and borders maintain their previously described relationships with width difference from Models 1 and 3. Two previously omitted variables are included in Model 4: trail grade ($p<0.043$) and landform grade ($p<0.001$). Landform grade has a negative beta coefficient (-0.433), indicating that as landform grades increase, trails' width differences decrease. Steeper trail sideslopes inhibit traffic, concentrating more traffic on a narrower bench. The managerial variable, trail grade, has a positive beta coefficient (0.532), indicating as trail grades increase, trails become wider than intended. As previously noted, this is likely attributed to increased lateral wandering involved with selecting the easiest route up or down a steeper trail alignment. The adjusted R-square value for Model 4 indicates that these variables collectively account for approximately twelve percent of the variation in trail width difference; Cohen's effect size estimate for this model is medium, the largest of the four width difference models.

Collectively, these results suggest that level of trail use, rugosity, and trail borders are the more influential variables affecting trail width and width difference (Tables 2.3 and 2.4, Model 4). These results are not surprising, given the strong causal linkage between human behavior and trail width. Rugosity is the most influential variable, likely because visitors respond directly to the terrain in front of them, widening a trail when the tread is less appealing for traffic than trailside conditions. Other factors, such as trail grade and landform grade or position, influence behavior only part of the time when more extreme conditions compel altered behavior. Trail borders are effective but their use is expensive and less appropriate in primitive settings.

Models failed to show significance for several variables that we expected to influence trail width and width difference. Most notably, slope ratio and TSA failed to demonstrate significance in the models. Slope ratio is calculated as the quotient of trail grade and landform grade; the interrelatedness of these three variables confounds the modeling results. Both TSA and LFP assess the position of the trail to local topography; our models show the categorical variable LFP as a significant influence on trail width and width difference, but fail to find significance in the

TSA variable. The modeling results are confounded by the inclusion of these highly correlated variables.

Interactions

Regression and ANOVA analyses revealed an interesting interaction between landform grade and position on their influence of trail width. Drawing from the environmental models, we see that landform position has significant influence on trail width and width difference and landform grade was included in the overall model for width difference. To investigate an expected interrelationship between these variables we plotted estimated marginal means for both trail width and width difference by landform grade (classed), and landform position (Figure 2.3). These plots confirm our expectations. Sidehill and fall-aligned trails have similar intermediate trail width and width difference means at lower landform grades (0-10%). As landform grades increase, we see mean trail width and width difference values diverge: sidehill means trend smaller, while fall-aligned trail means trend larger.

For fall-aligned trails, increasing trail grades exacerbate problems with trail widening. As described by Leung and Marion (1996), the flatter sideslopes of fall-aligned trails, relative to the plane of the tread, offer little resistance to trail widening. For sidehill trails, increasing the grade of the sideslope terrain further confines visitor traffic to the intended tread, a topographic effect that is only possible on sidehill alignments. These interrelationships also explain why trail designers should avoid locating trails in flatter terrains. Treads in flatter terrain become incised due to soil compaction and displacement, collecting water that is difficult to drain, contributing to trail muddiness, which is circumvented by visitors, promoting trail widening (Calais and Kirkpatrick 1986; Marion 1994). Only by moving a trail to sloping terrain with a sidehill alignment does it become possible to remove water from the tread easily. Trail guidance frequently suggests avoiding flat terrain to minimize these problems with poor drainage, muddiness, and trail widening (Birchard and Proudman 2000; Marion and Wimpey 2007).

Conclusion

This study applied relational analyses to investigate how use, environmental and managerial variables influence trail widths at Acadia National Park. The literature review and analyses in this paper more clearly describe the role and influence of an array of factors that can assist managers in selecting appropriate and effective management actions to reduce the lateral dispersal of hikers. 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 were described. However, trail widening behaviors can be substantially modified by a number of environmental and managerial factors.

This study provided clear evidence that the 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. A principal factor subject to managerial control is tread rugosity or roughness, which causes avoidance behaviors that widen trails when hikers travel along trailsides that offer easier passage. These analyses suggest that managers can limit trail widths by adequately addressing other forms of trail impact, such as muddiness, or erosion with excessive rutting, exposed roots, and stoniness. 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. Other factors, such as low impact educational practices and regulations, may also be effective, though these were not investigated in this study.

A unique innovation in this study was the inclusion of trail width difference as a dependent variable in relational analyses. Comparing the actual width of the trail to the intended width of the trail allows managers and researchers a unique perspective that clearly demonstrates avoidable impacts associated with trails that are wider than intended. Future research should attempt to procure and use intended width data from land managers when available due to the additional insights provided. Further, we note that failure to account for differences in intended trail widths can provide a confounding influence in relational analyses. Acadia NP data show that gravel surfaced trails are the widest with respect to trail width; however, comparison to the intended widths provided by the NPS reveal little variation from their intended widths. Further, wider trail widths may be intended for a variety of reasons: to accommodate higher levels of traffic, users with disabilities, or to permit vehicle access for emergency or resource protection functions. Ignoring the intended width of these trails in research can obscure the true relationships and implications of findings.

We note several limitations in this study that influence our findings and provide guidance for future studies. The unique topography and geology of ACAD provide for fantastic recreation opportunities and views; however, these unique features may limit the applicability of our findings to dissimilar areas. For example, the substantial topographic relief and rockiness within the park made muddiness a rare possibility along most park trails, preventing analyses that examine relationship between muddiness and trail widening. Previous research has shown trail muddiness to be a major cause of trail widening (Calais and Kirkpatrick 1986; Marion 1994). Future research in a variety of locations should seek to include muddiness in investigations of trail width and width difference.

Given the prominence of tread roughness in our findings, we recommend that future research include this variable and seek to develop additional objective and efficient techniques for assessing tread roughness as it relates to the obstruction of trail traffic. Bayfield (1973) employed quadrats on the tread and in adjacent areas, we employed a linear system to calculate rugosity as a byproduct of trail soil loss estimates across trail transects. Measures should be applied to trail treads and adjacent trailside locations to permit the best evaluation of this under-investigated topic.

Acknowledgements

The authors would like to thank the following people for their involvement in this project:

Logan Park for his assistance in field data collection and GIS analysis.

Charlie Jacobi for his input, coordination and development of use and intended width data.

Karen Anderson for her assistance in supplying NPS GIS data to the project.

Laura Freeman for her statistical consulting through out the project.

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CHAPTER 3 A SPATIAL EXPLORATION OF INFORMAL TRAIL NETWORKS WITHIN GREAT FALLS PARK, VA

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Abstract

Informal (visitor created) trails represent a threat to the natural resources of protected natural areas around the globe because they remove vegetation, displace wildlife, alter hydrology, alter habitat, spread invasive species, and fragment landscapes. This study examines informal and formal trails within Great Falls Park, VA, a sub-unit of the George Washington Memorial Parkway, managed by the U.S. National Park Service. In order to better understand the impacts associated with informal trails on protected natural areas, this study sought to answer three specific questions: 1) Are the physical characteristics and topographic alignments of informal trails significantly different from formal trails, 2) Can landscape fragmentation metrics be used to summarize the relative impacts of formal and informal trail networks on a protected natural area?, and 3) What can we learn from examining the spatial distribution of the informal trails within protected natural areas?

Statistical comparisons between formal and informal trails in this park indicate that informal trails have less sustainable topographic alignments than their formal counterparts, indicating they are more impacting to the natural resources. Spatial summaries of the lineal and areal extent and fragmentation associated with the trail networks by park management zones compare park

management goals to the assessed attributes. Hotspot analyses highlight areas of high trail density within the park and findings provide insights regarding potential causes for development of dense informal trail networks.

Keywords: Trail, Informal Trail, Landscape Fragmentation, Recreation Impact

Introduction

This study builds upon past research and employs a census survey of formal and informal trails within a park to further develop our understanding of informal trails and their impacts on protected natural areas. Specifically, this research seeks to further our understanding of informal trails impacts by answering three key questions:

- *Are the physical characteristics and topographic alignments of informal trails significantly different from formal trails?*
- *Can landscape fragmentation metrics be used to summarize the relative impacts of formal and informal trail networks on a protected natural area?*
- *Can hotspot analysis aid in visualization of avoidable impact associated with informal trails?*

Protected natural areas around the world are established and managed to accommodate visitor access and recreation while protecting natural and cultural resources from degradation. In the United States, many of the most highly visited protected areas are managed by the National Park Service (NPS) and guided by laws directing park managers to balance visitor use with natural resource protection (NPS 2001). 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 and Cole 1998; Marion and 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 and Leung 2004; Olive and Marion 2008). 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. Occasionally, further hardening, such as adding gravel, stepping stones, or boardwalks, is necessary to prevent degradation of the area from the intended use.

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 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 off-trail traffic can wear down vegetation and organic litter to create visible informal (visitor-created) trail networks (Weaver and Dale 1978; Thurston and Reader 2001). 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, Aviles et al. 1991; Roovers, Bossuyt 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 and Swearingen 1992) and site management (Matheny 1979; Johnson, Bratton et al. 1987; Sutter, Benjamin et al. 1993; Park 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, Lowther et al. 1993; Marion and Cahill 2004; Manning, Jacobi et al. 2006; Marion and Hockett 2006; Wood, Lawson et al. 2006). However, few studies have extensively mapped or investigated the resource impacts of informal trail networks within protected natural areas (Cole, Watson et al. 1997; Leung 2002; Marion and Hockett 2006; Leung 2007), although several have collected informal trail counts in conjunction with campsite, recreation site, or formal trail inventories (Marion 1994; Leung and Marion 1999; Dixon, Hawes et al. 2004; Marion and Cahill 2004; Wood, Lawson et al. 2006). The lack of comprehensive research on informal trails is surprising considering the numerous threats these trails represent to natural resources.

Trails impact local and regional ecology by adversely impacting native flora, fauna, and soils through local trampling-related disturbance and possible introduction or dispersal of exotic and invasive species (Cole and Knight 1990; Benninger-Truax, Vankat et al. 1992; Johnson 1992; Adkison and Jackson 1996; Bhuju and Ohsawa 1998; Potito and Beatty 2005; Hill and Pickering 2006). Furthermore, trail-based recreation can adversely affect wildlife in several ways, including spatial and temporal displacement (Cole and Knight 1990; Knight and Cole 1991; Miller, Knight et al. 1998; Taylor and Knight 2003). For example, Taylor and Knight (2003) found that three ungulate species were likely (96% flush rate for mule deer) to flee from trail users if they were within 100m of the trail. Miller et al (1998) found decreased presence of nesting birds near trails in grassland ecosystems. Trails can alter hydrology by intercepting and channeling surface water (R. A. Sutherland 2001), and fragment the landscape with potential barriers to flora and some small fauna (Leung 2002; Leung 2007).

Several studies show that proper trail design and construction principles minimize adverse impacts to natural resources and reduce the need for trail maintenance (Leung and Marion 1996; Marion and Leung 2004; Marion 2006; Olive and Marion 2009). 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; however, this assertion has not been demonstrated with empirical data. 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 and Leung 2004).

Fragmentation of the landscape by roads and development has long been a concern of land managers at a variety of spatial scales from global, to regional, to local (Harris 1984; Ripple, Bradshaw et al. 1991; Saunders, Hobbs et al. 1991; Matlack 1993; Geoghegan, Wainger et al. 1997; Swenson and Franklin 2000; Carsjens and van Lier 2002; Jaeger, Raumer et al. 2007). Fragmentation is a multi-pronged threat to natural resources that affects wildlife by reducing, expanding or disturbing viable habitat (Saunders, Hobbs et al. 1991; David G. Haskell 2000) and alters local ecosystems by disturbing native vegetation and potentially introducing non-native or invasive plant species (Saunders, Hobbs et al. 1991; Brothers and Spingarn 1992; Hill and Pickering 2006). Natural surface forest roads built as extraction and access routes have been shown to have far-reaching impacts on natural systems through their fragmentation of the landscape (Mader 1984; Rebecca A. Reed 1996; Forman and Alexander 1998; David G. Haskell 2000; Stephen C. Trombulak 2000; Watkins, Chen et al. 2003). Fragmentation indices have been developed to quantify and objectively describe the landscape patterns and impacts of human-associated development (Ripple, Bradshaw et al. 1991; Matlack 1993; Geoghegan, Wainger et al. 1997; Jaeger 2000; Carsjens and van Lier 2002; Staus, Strittholt et al. 2002; Moser, Jaeger et al. 2007; Jaeger, Bertiller et al. 2008). These indices are applied at a wide variety of scales to investigate how proposed and existing development may affect natural systems.

Scientists and park managers can apply fragmentation indices to quantify and describe the fragmentation of protected lands by formal and informal trail systems and other developments. A study of recreational impacts to Boston Harbor Islands National Park Area reported the density and lineal extent of informal trails within the park and investigated their proximity to rare threatened and endangered plant and animal species (Leung 2003). A recent study of meadow fragmentation by informal trails within Yosemite National Park uses landscape fragmentation indices to assess and monitor natural resource impacts (Leung and Louie 2008).

Study area

Great Falls Park, Virginia (GFP), a subunit of the George Washington Memorial Parkway, is an approximately 325ha (800-acre) park located along the Potomac River 15 km (9.3 miles) upstream from Washington, DC. The park is located in a densely populated region of the Mid-Atlantic United States. The park attracts many repeat local visitors from the region, and tourists from around the world. In 2007, the NPS estimated annual visitation at just more than one-half million visitors (NPS 2007). The rare and unique ecosystems of the park, which are created by its geology, flood regime, and location at the 23m (76ft) tall Great Falls and the tall cliff walls of the Mather Gorge, are home to more than two-hundred local, national and global rare threatened and endangered plant and animal species (NPS 2007). Cultural resources within the park include the historic ruins of George Washington's "Patowmack" Canal and the town of Matildaville (NPS 2007). The park has established four management zones: the canal, cultural & natural, developed, and Mather Gorge (Figure 3.1 and Table 3.1).

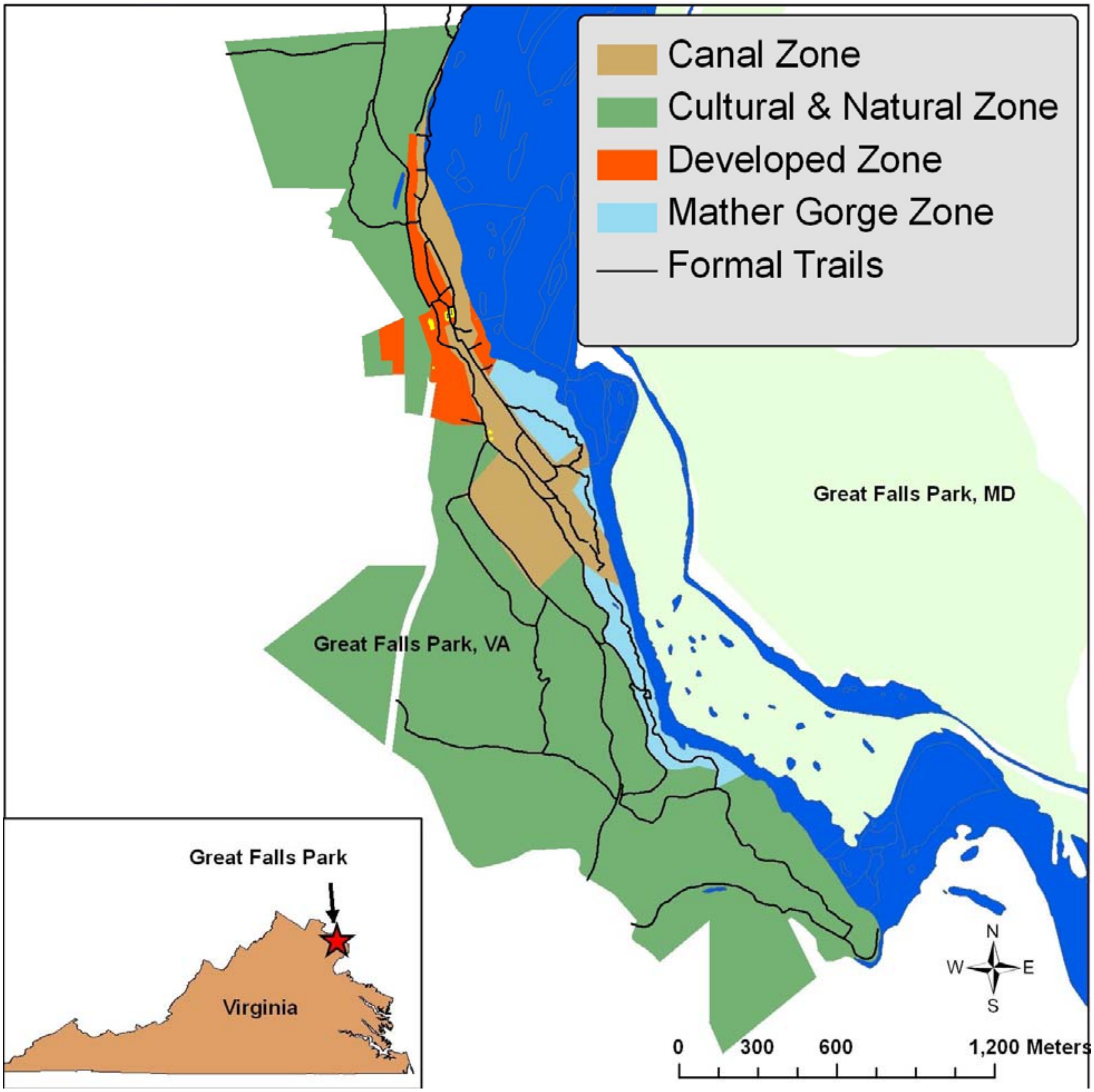

Figure 3.1 *Management zones and trails of Great Falls Park, VA*

Table 3.1 *Great Falls Park: Management zone descriptions*

Low ← Recreation Infrastructure → High	**Zone**	**Description**
	Developed Zone 11.7 ha (29 acres)	• Area where park administration, maintenance, parking and visitor facilities are located • Located to protect cultural and natural resources while providing convenient locations for facilities
	Canal Zone 30 ha (74 acres)	• Area around Patowmack Canal • Historical "ruins" of Matildaville • Principle focus on preservation of historic canal resources • Preservation of these sites including mowing and landscaping alter the landscape significantly
	Mather Gorge 16.2 ha (40 acres)	• Areas adjacent to the Potomac River within Mather Gorge • Focus on preservation of cultural and natural resources while providing "safe" recreational opportunities in designated areas (rock climbing, rafting, kayaking)
	Cultural & Natural Zone 235.1 ha (581 acres)	• Largest zone of the park • Primary goal of preserving cultural and natural resources • Contains some historic ruins and park infrastructure

GFP visitors engage in a variety of recreational activities within the park, including: sightseeing, hiking, rock climbing, picnicking, nature study, trail running, kayaking, rafting, fishing, and horseback riding. Most of the visitors rely on the park's trail system to provide access to specific areas within the park. The formal (designated) trail system includes eleven trails totaling approximately 16 kilometers (10 miles) (NPS 2007).

Heavy park visitation, primarily on weekends, can lead to crowding at facilities within the park, including the parking and picnic areas, scenic overlooks, and along trails (NPS 2007). Off-trail traffic by visitors exploring and accessing a variety of locations not reached by the formal trail system has led to the development of extensive informal trail networks. Informal trails are so prevalent and established in portions of the park that many visitors likely believe them to be part of the park's formal trail system.

Methods

Statistical Analysis

All data were converted to metric units where appropriate, data were then imported into SPSS 16.0 for statistical analyses. A classed landform grade variable was generated from landform grade using logical break points. Dependent variables were plotted and reviewed for normality using residual plots. For the comparison of informal and formal trails, parametric statistical tests (ANOVA and T-tests) allowed for contrasts of TW, LG, TG, and SR values. Alpha was set to 0.05 for 95% confidence in the statistical comparisons. A Tukey adjustment was used to correct the alpha level for the multiple contrasts. Fragmentation analyses were limited to comparison of summary statistics by management zone, including difference and % difference values. Hotspot analyses output were visually reviewed and classified using natural breaks (6 classes).

NPS staff provided several spatial datasets for GFP; these included a 1.5m (5ft) contour elevation dataset, a formal trail layer representing all maintained trails within the park, and a layer of the management zones of the park. We used ESRI's ArcMAP 9.3 spatial analyst tools to create a triangulated irregular network (TIN) from the 1.5m contour dataset. This TIN contains elevation, landform slope and aspect data for park topography. Additional formal and informal trail data were collected using a Trimble GPS as part of a census survey of the trails within the park. Formal trails were point sampled using methods adapted from previous formal trail research in US National Parks (Marion 2006; Olive and Marion 2009). Tread width data from formal trail point collection were aggregated and spatially joined to the linear formal trail features for analyses.

Informal trails were collected as linear features using a Trimble GeoXT GPS with external Hurricane antenna. All GPS data were post-processed using Trimble's Pathfinder Office 4.0 and base station data from the nearest available Continuously Operating Reference Stations (CORS). Two informal trail condition attributes were assessed during field collection: condition class (CC), as previously implemented in rapid assessment surveys of formal trails (Marion, Leung et al. 2006), and an estimate of the average tread width (TW) of the informal trail segment. Condition class ranges from 1-5 with an increase in value associated with greater departures from natural conditions (Table 3.2). A new informal trail segment was designated and assessed when a change in condition class was noted in the field. Point data were collected at formal and informal trail junctions and at endpoints to aid in the GIS editing process.

Table 3.2 *Informal trail condition class descriptions*

Condition Class	Description
1	Trail distinguishable; slight loss of vegetation cover and/or minimal disturbance of organic litter
2	Trail obvious; vegetation cover lost and/or organic litter pulverized in center of tread in most places
3	Vegetation cover and organic litter lost across the majority of the tread
4	Soil erosion in the tread beginning in some places
5	Soil erosion is common along the tread

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 accuracy and provide spatial context. Due to the nature of GPS data, the shapefiles required extensive editing to create an accurate representation of the trail networks in ArcMAP 9.3. The majority of this work involved snapping informal trail segment endpoints to the formal trail network and other informal trail end points at junction points. When editing was complete, shapefile datasets were used in conjunction with NPS-provided data to conduct three analyses: 1) informal/formal trail comparisons, 2) landscape fragmentation evaluations, and 3) an informal trail hot spot analysis.

Comparison of informal and formal trails

Past research has shown that two key trail design variables heavily influence the rate of trail degradation: trail grade (TG) and trail slope alignment (TSA) (Leung and Marion 1996; Marion 2006; Marion, Leung et al. 2006; Marion and Wimpey 2007; Olive and Marion 2009). Both variables relate to how a trail is topographically aligned. TG is a measure of how steep the trail is, generally expressed as percent grade (rise/run). TSA is calculated as the difference between the azimuth of the landform fall-line and the azimuth of the trail as it crosses the fall-line; values for TSA range from zero (trail is aligned parallel to the landform fall-line) to ninety (trail is parallel to the contour). Slope Ratio (SR) is a trail design variable calculated as TG divided by landform grade (LG) (IMBA 2004; Parker 2004; IMBA 2007; State of Minnesota 2007); this measure is analogous to TSA in that it assesses how the trail is aligned with respect to the fall-line. SR ranges from 0 to 1; higher values indicate TG is approaching LG.

Points were placed at 1m spacing along formal and informal trail shapefiles using a macro called "PointsalongPoly" (Hitchen 2007). At each point, the LG was extracted from the TIN created from NPS 1.5m contour data. We extracted TG for each point by spatially joining the points to "running slope" data for the trail networks created using a macro called "RunningSlope" (Chasen 2007). The "RunningSlope" macro calculates the slope along a line feature by referencing an elevation dataset (the TIN mentioned previously) and calculating a slope at a specified distance along the line or between line vertices. SR was calculated as the quotient of TG and LG. Additional attribute data was added to the points; including the type of trail they belong to (formal or informal) and trail width. Points that fell along informal trails were assigned their CC value. The attribute table of the point shapefile was exported as a .dbf for further statistical analyses in SPSS. Additional classing of these data by LG was conducted to aid in visualization and investigation of relationships and trends in the data. Classification was made using logical breakpoints between classes (Table 3.3).

Table 3.3 *Landform grade classes*

Landform Grade	Class
0 – 1%	0 (Flat)
1 – 3 %	1 (Shallow)
3 – 5%	2 (Low)
5 – 20%	3 (Moderate)
20 – 45%	4 (Steep)
45+%	5 (Extremely Steep)

NPS management zones were used to summarize and compare the lineal and areal extent of impacts associated with formal and informal trails in sub-regions of the park. Areal extents were calculated by multiplying TW by trail length. Additional summaries compared the lineal and areal extent of trail impacts by CC and trail type.

Landscape fragmentation

To analyze landscape fragmentation within GFP by formal and informal trails we implemented methods similar to Leung and Louie's (2008) Yosemite National Park protocol. The park boundary polygon was used as a base layer, from which we removed park infrastructure, including roads. Removal of these features was accomplished by intersecting the features in ArcMAP 9.3 and manually selecting and deleting polygons that correspond to the infrastructure, the remaining polygons represent the natural portions of the park that have the potential to be further impacted and fragmented. We then created one-half trail width (TW) buffers on the formal and informal trail segments. The resultant buffers represent the areal impact associated with the trails within GFP. The buffered trail segments were intersected with and removed from the "no roads" shapefile to create shapefiles representing the park's fragmentation by only formal trails and both formal and informal trails, respectively. These shapefiles were used to calculate the following landscape fragmentation metrics: Number of patches (N), Mean Patch Size (MPS), Largest Patch Index (LPI), Mean Perimeter: Area Ratio (MPAR) (Table 3.4). The NPS management zone layer was used to summarize and compare these fragmentation metrics across park sub-regions.

Table 3.4 *Landscape fragmentation metrics*

Number of Patches (N)	Count of patches
Mean Patch Size (MPS)	Average size of patches in m^2
Largest Patch Index (LPI)	Largest patch's area / sum all patch areas
Mean Perimeter: Area Ratio (MPAR)	Average of all patches' perimeter/area

Hot spot analysis

Hot spot analysis used ArcMAP 9.3's spatial analyst line density tool to create a raster dataset representing the density of trails within each cell. Cell size was set to 10x10m for visualization and two analyses were run to compare the lineal and areal densities of trails within GFP. Output was clipped to the boundary of GFP. The resultant datasets show the relative trail density hotspots within the park; hotspots were visually inspected to investigate potential causes. Hotspot analysis allows us to look at the relative densities of informal trails across the park.

Results

Comparison of informal and formal trails

Informal trails within GFP have higher grades, are located in steeper terrain, are more closely aligned to the fall-line, and are narrower, than formal trails (Table 3.5). T-test comparisons of mean values for LG, TG, SR and TW for informal vs. formal trails showed significant differences for all tests ($p<0.001$, equal variances not assumed).

Table 3.5 *Summary of key formal and informal trail attributes*

Trail Type		Landform Grade	Trail Grade	Slope Ratio	Trail Width
Formal Trails	*Mean*	13.73	5.83	.54	2.41
	N	20302	20302	20302	20302
	Std. Dev.	17.594	9.232	.372	.912
Informal Trails	*Mean*	19.54	11.66	.65	.86
	N	17076	17076	17076	17076
	Std. Dev.	22.677	16.062	.334	.629

We compared values for TG across LG classes to investigate relationships (Figure 3.2a). A one-way ANOVA test indicates that mean TG of informal and formal trails are not significantly different from each other (p>0.05, Games-Howell Test Statistic) in flat and shallow LG classes, while mean TG values for informal trails are significantly higher than for formal trails (p<0.001, Games-Howell Test Statistic) in all other LG classes.

A related comparison of mean SR across LG classes (Figure 3.2b) found that the mean SR of informal and formal trails are not significantly different from each other (p>0.05, Games-Howell Test Statistic) in the flat LG class, while mean SR values for informal trails are significantly higher than formal trails (p<0.001, Games-Howell Test Statistic) in all other LG classes.

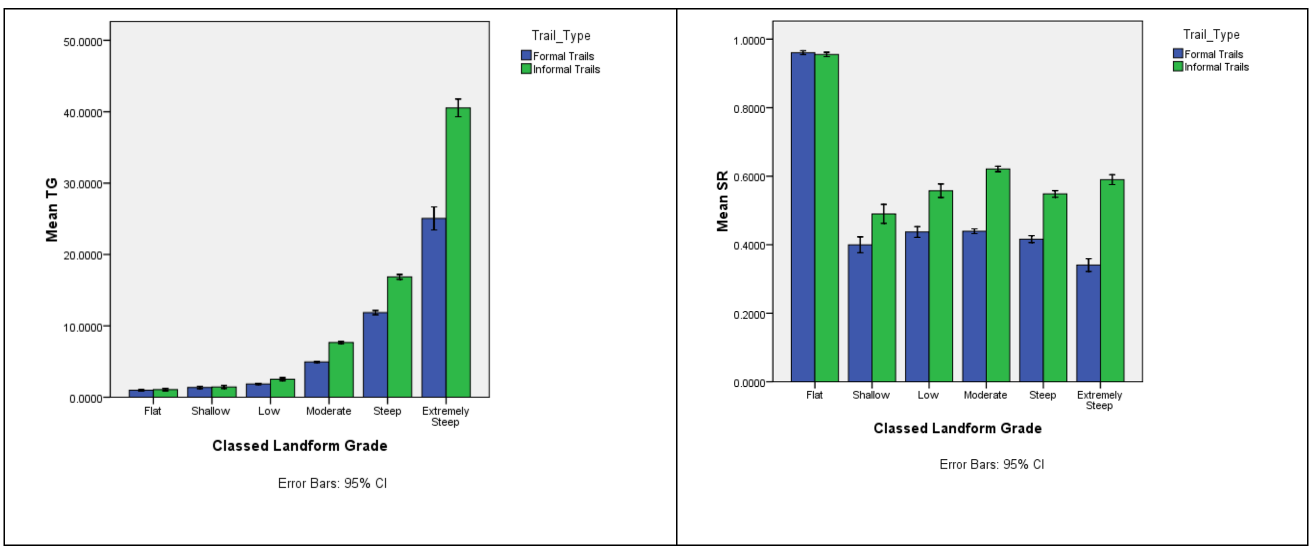

Figure 3.2 *Mean trail grade (a) and slope ratio (b) plots by landform grade class*

Additional analyses looked at the differences in mean TG, LG, SR and TW of trails based on condition class (Figures 3.3 a-d and Table 3.6). The means for TG, LG, and TW increase as CC increases; a series of one-way ANOVAs indicates that TG, LG and TW values are significantly different (p<0.001, Games-Howell test statistic) for CC 2 to CC 5. However, the means for SR do not appear to have a clear trend as CC increases and a one-way ANOVA indicates that SR values are not significantly different (p>0.05, Games-Howell test statistic) for CC 2 to CC 5. A low "N" for CC 1 trails (2 segments, 17 sample points) makes statistical contrasts difficult for this class.

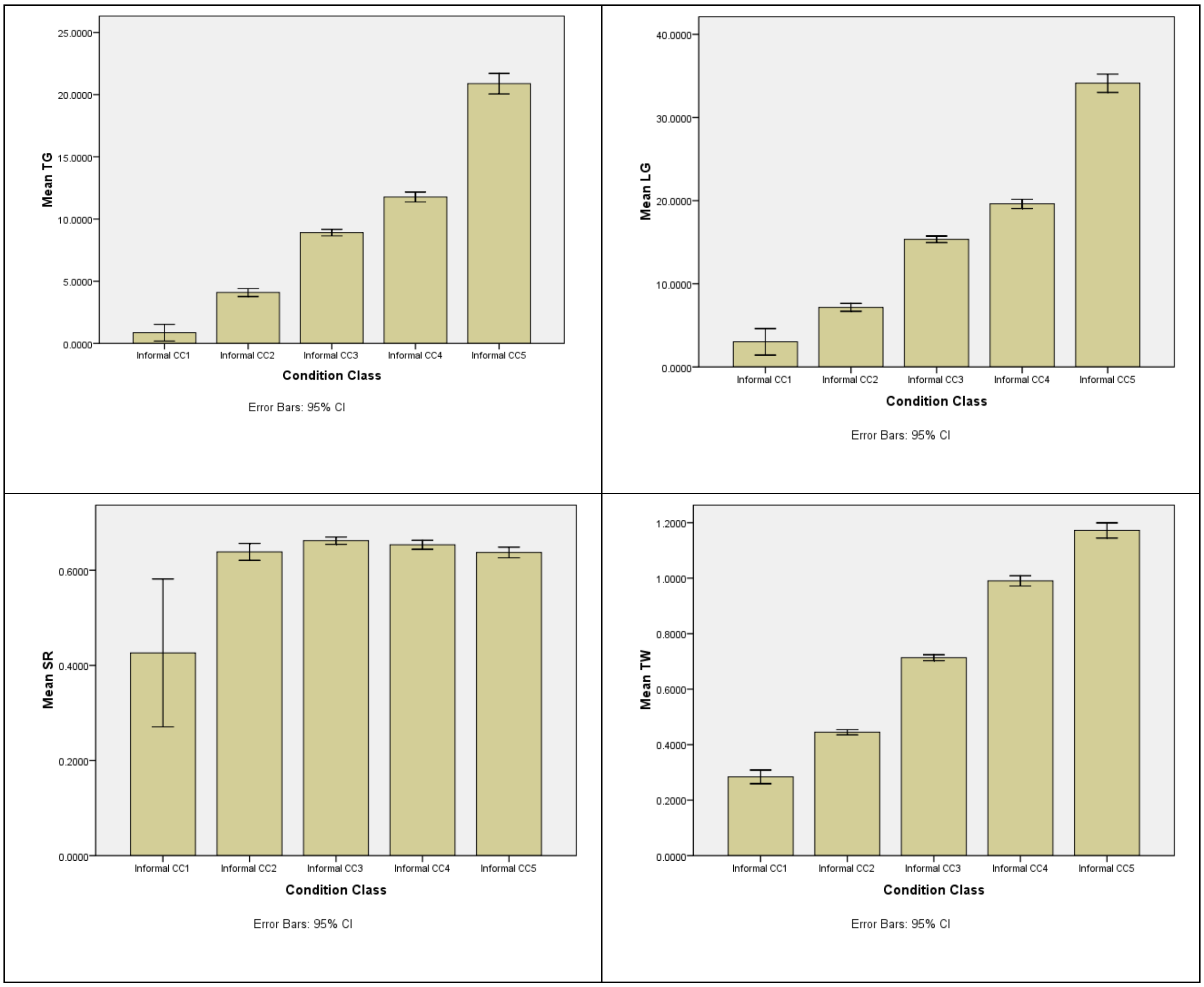

Figure 3.3 *Mean trail grade, landform grade, slope ratio and trail width plots by condition class*

Table 3.6 *Mean trail grade, landform grade, slope ratio and trail width summaries by condition class*

Trail Class	N	Mean TG (% grade)	Mean LG (% grade)	Mean SR	Mean TW (m)
Formal[1]	20302	5.8[a]	13.7[a]	0.54[a]	2.41[a]
Informal (all)[2]	17076	11.7	19.5	0.65	0.86
CC 1	17	0.9[b]	3.0[b]	0.43[a,b]	0.28[b]
CC 2	1427	4.1[c]	7.2[c]	0.64[b]	0.44[c]
CC 3	7472	8.9[d]	15.3[d]	0.66[b]	0.71[d]
CC 4	4807	11.8[e]	19.6[e]	0.65[b]	0.99[e]
CC 5	3353	20.9[f]	34.1[f]	0.64[b]	1.2[f]

1 - Superscripts represent unique groupings within each column based on the Games-Howell test statistic, alpha=0.05 (rows with the same letter are not significantly different from each other)

2 - this row excluded from groupings

The lineal and areal extent of impact by formal and informal trails was summarized by park management zone. Management zones were ranked based on the extent to which they depart from natural conditions. We report the lineal and areal extent of formal and informal trails by zone in Table 3.7. We have also normalized these indicators by the total size of each management zone, so that comparisons of relative levels of impact can be made. The greatest lineal and areal extents of formal and informal trails are in our largest zone, the Cultural & Natural Zone. The highest relative level of lineal impact associated with informal trails is found in the Mather Gorge Zone. The highest relative level of areal impact associated with informal trails is found in the Cultural & Natural Zone.

Table 3.7 *Formal and informal trail impacts summarized bypark management zone*

Impact Indicators	Park Zones			
	Developed (11.7 ha)	**Canal** (30.0 ha)	**Mather Gorge** (16.2 ha)	**Cultural/Natural** (235.1 ha)
	High	*← Recreation Infrastructure →*		*Low*
Aggregate Length (m)				
Formal Trails	1509	3811	1844	10,288
Informal Trails	443	4538	5532	5813
Disturbance Area (m^2)				
Formal Trails	3880	10,962	3349	24,970
Informal Trails	261	3962	4335	5647
Lineal Extent (m/ha)				
Formal Trail Length	129	127	114	44
Informal Trail Length	38	151	341	25
Disturbance Density (m^2/ha)				
Formal Trails	2571	2876	1816	2427
Informal Trails	589	873	784	971

Fragmentation

The four landscape fragmentation indices calculated for the formal and informal trail networks are reported by management zone in Table 3.8. Management zones are ranked based on the extent to which they depart from natural conditions. We see an increase in the number of patches present for all zones when we compare formal trail fragmentation to fragmentation including all trails (formal and informal). The Mather Gorge zone has the largest numeric (152) and proportional (+1,900%) increase in the number of patches. MPS decreases in all management zones when we compare formal trail fragmentation to fragmentation including all trails. The Mather Gorge Zone sees the biggest decrease in MPS proportionally (-95.3%), while the Cultural & Natural Zone sees the largest numeric decrease in MPS (-81,006m^2). LPI decreases for the Developed and Mather Gorge Zones, while it increases for the Canal Zone and the Cultural & Natural Zone when we compare formal trail fragmentation to fragmentation including all trails. MPAR increases for all zones when we compare formal trail fragmentation to fragmentation including all trails. We see the largest proportional (+1,211%) and numeric (+1.09) increases of LPI in the Mather Gorge Zone.

Table 3.8 *Landscape fragmentation indices by park management zone*

Fragmentation Indices	**Park Zones**			
	Developed (11.7 ha)	**Canal** (30.0 ha)	**Mather Gorge** (16.2 ha)	**Cultural/Natural** (235.1 ha)
	High	*← Recreation Infrastructure →*		*Low*
Number of Patches (N)				
Formal Trails	15	25	8	22
All Trails (% change)	30(+100%)	157(+528%)	160(+1900%)	96(+336%)
Mean Patch Size (MPS) (m^2)				
Formal Trails	5,214	11,095	19,428	104,805
All Trails(% change)	2,580(-51%)	1,716(-85%)	921(-95%)	23,799(-77%)
Largest Patch Index (LPI)				
Formal Trails	0.35	0.35	0.27	0.16
All Trails(% change)	0.30(-14%)	0.36(+3%)	0.20(-26%)	0.17(+6%)
Mean Perimeter: Area Ratio (MPAR) (m/m^2)				
Formal Trails	0.17	0.22	0.09	0.15
All Trails(% change)	0.44(+159%)	1.16(+427%)	1.18(+1211%)	0.89(+493%)

Hot spot Analysis

To look at the spatial distribution and density of trails objectively, we created a 10x10m raster dataset within the GFP boundaries. A density of formal and informal trails was calculated for each cell using an 80m search radius. Two iterations were conducted: one using the lineal extent of informal trails, and the second using the lineal extent of all trails. The resultant raster datasets were classified and displayed to visualize trail "hotspots" within the park **(**Figure 3.4**)**. Visual inspection of trail networks within hotpots, coupled with reviews of high resolution satellite imagery, can provide managers with unique insights regarding the spatial arrangement and potential management of informal trails. The most intense informal trail density hotspot is located in the center of the park and overlaps the Mather Gorge and Canal Zones; these are trails near the cliff-tops overlooking the Potomac River in a very high use region of GFP. Lineal hotspot analysis including all trails shows similar hotspots along the Potomac River and Difficult Run, and several moderately dense hotspots associated with trail junctions.

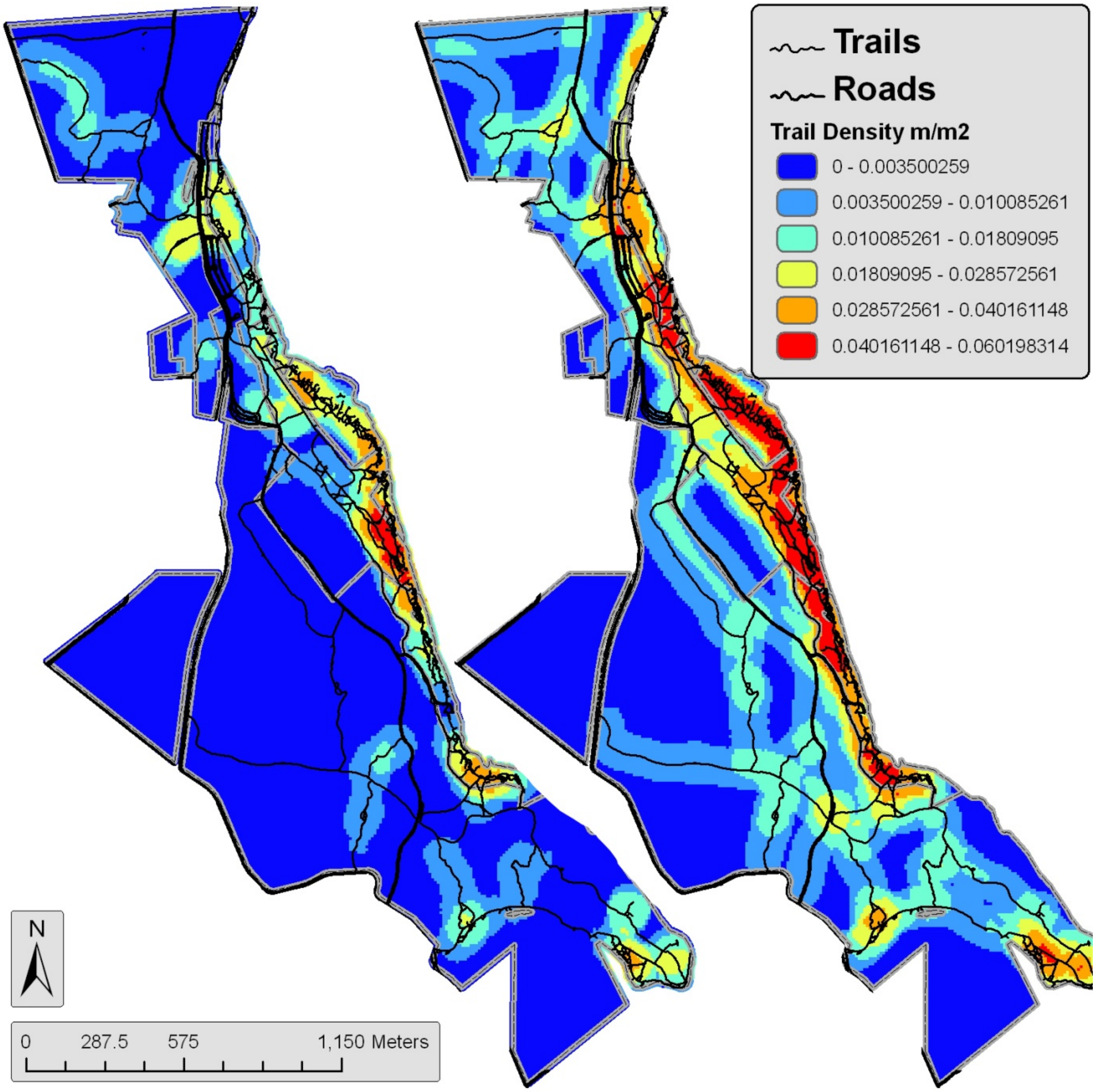

Figure 3.4 *Trail densities within Great Falls Park: informal (left) and all trails (right)*

Discussion

Comparison of informal and formal trails

We expect that visitors either lack knowledge of sustainable trail design principles or will fail to apply them due to their prevailing interest in directly or quickly accessing an area of interest. Thus we also expect informal trails to have design attributes that are less sustainable than formal trails. Analyses of empirical data are consistent with these expectations, revealing statistically significant ($p<0.001$) differences between informal and formal trails with respect to mean TG, LG, SR and TW. Informal trails are on average twice as steep as formal trails within GFP, with mean TG values of 11.7% and 5.8% respectively (Table 3.5). Prior research has shown that as TG increases, tread soil loss also increases, contributing to greater sediment run-off and increased maintenance costs (Leung and Marion 1996; Goeft and Alder 2001; Dixon, Hawes et al. 2004; Marion 2006; Olive and Marion 2009). Trail design, construction and maintenance manuals commonly recommend minimizing TG to avoid problems with soil erosion and displacement (McCoy and Stoner 1991; Birchard and Proudman 2000; IMBA 2004; Hesselbarth, Vachowski et al. 2007; IMBA 2007; State of Minnesota 2007). While specific recommendations for TG vary, current guidance generally recommends not exceeding an average grade of 10% for multi-use trails. Since informal trails lack the benefit of tread designs or maintenance actions that remove water from their treads, their average grade should be much lower, perhaps 6%. Regardless, the mean TG of informal trails in GFP exceeds both values, indicating they are susceptible to degradation.

LG means are also higher for informal trails than formal trails within GFP, with mean LG values of 19.5% and 13.7% respectively. These values indicate that informal trails are located in steeper terrain than formal trails. Investigating TG means across LG classes (Figure 3.2a), we find that TGs of informal trails increase at a much higher rate than their formal trail counter parts as LG class increases from flat to extremely steep. These findings suggest that off-trail hikers are willing to negotiate steeper terrain than would be considered prudent by trail professionals.

Current trail design, construction and maintenance manuals recommend keeping SR below a certain threshold; a commonly applied SR guidance is the “half rule” (IMBA 2004; IMBA 2007) which recommends keeping TG less than ½ of LG. While SR has not yet been empirically investigated in the scientific literature, TSA, which is roughly analogous to SR, has been demonstrated to be a significant predictor of trail degradation (Leung and Marion 1996; Marion 2006; Olive and Marion 2009). Both measures reflect the trail’s alignment to the prevailing landform grade. A recommendation to avoid a SR of 0.50 is equivalent to a TSA of 45^{o}; a very poorly designed fall-line trail would have SR values in excess of 0.75 and TSA values less than 22.5^{o}.

Mean SR values for both informal and formal trails within GFP exceed the half rule guidance, with means of 0.65 and 0.54 respectively. Informal trails exceed the guidance by a larger margin, implying that they are more likely to degrade than formal trails, particularly when their lack of tread drainage is considered. An examination of SR differences between informal and formal trails across LG classes (Figure 3.2b), reveals that SRs for formal trails in sloping terrain are consistently lower than 0.50, while informal trail SRs are consistently greater than 0.50 (Figure 3.2b). Trails in flat terrain are problematic regardless of SR values, because they are susceptible to widening and difficult to drain (IMBA 2004; IMBA 2007). Soil compaction and erosion make treads lower than the surrounding land, so that water collects and forms mud, which in turn is circumvented by trail users.

Informal trails are significantly narrower than formal trails within GFP, with mean values of 0.86m and 2.41m respectively. We suggest several reasons for this finding: 1) several formal trails follow historic roadways and towpaths associated with activity around the Patowmack Canal and Matildaville, 2) park staff maintain several formal trails for four wheeled vehicle access for maintenance and river rescue access, 3) trail maintenance includes the trimming of obstructing trailside vegetation, and 4) though visitor use data for formal and informal trails is unavailable, observations suggest that formal trails receive much higher levels of use. In particular, we expect that the widths of informal trails are limited by obstructing trailside vegetation, which is not trimmed by park staff. Furthermore, while not objectively documented, observations reveal that formal trails often receive use by large groupings of hikers, while informal trails are travelled single file by individuals or small groups.

We examined the differences within informal trails by CC by comparing mean TG, LG, SR and TW values of the classes (Figure 3.3a-d). We see that informal trails above CC 1 violate the half rule with SR means above 0.6. Additionally, we see that CC 4 & CC 5 trails exceed the 10% average grade guidance; mean TG for CC 5 trails is 20.9% and 11.8% for CC 4 trails. Finally, both TG and LG increase significantly with increasing CC (Table 3.6), reflecting the greater potential for degradation of steep trail alignments and steep terrain. Couple this with the absence of planned grade reversals, outsloped treads, and water control features and we see a high potential for degradation of informal trails.

We summarize the lineal and areal extent of informal and formal trails by park management zone (Table 3.7) to examine the aggregate and relative extent of impact associated with trails in each zone. The Cultural & Natural Zone has the highest lineal and areal extent of aggregate impact for both formal and informal trails. However, if impacts are normalized to account for size differences between zones, the Mather Gorge Zone contains substantially greater impact for the lineal extent of informal trail impact. This is likely due to the greater traffic directed at gaining access to cliff-top vista sites, which often require off-trail traffic. Relative impact for the areal extent of informal trail trampling disturbance is greatest in the Cultural & Natural Zone, because of the greater frequency of wider informal trails in this zone. These findings are problematic because these two zones represent the less developed regions of the park where management goals emphasize preserving natural and cultural resources. The high absolute and relative levels of impact associated with informal trails in these zones suggest an inconsistency with management goals and the need for greater management attention. Landscape fragmentation indices provide another perspective for further investigating these issues.

Fragmentation

We calculated four landscape fragmentation indices within each GFP management zone. These indices allow us to further examine and describe the impacts associated with informal and formal trails in the park. Landscape fragmentation indices are used at multiple spatial scales to investigate how natural and anthropogenic features interact within the landscape; within GFP we examined how trails perforate, incise, dissect and shrink park management zones. The data for MPS (Table 3.8) show increasing average patch sizes when considering formal trails as we move from the Developed Zone to zones where resource protection is increasingly emphasized. These larger patches of "undisturbed" land therefore appear to be consistent with the management goals of preserving cultural and natural conditions within these zones.

When landscape fragmentation is assessed for formal and informal trails together, MPS values decrease across the zones, with the largest reduction (-95%) in the Mather Gorge Zone. This finding is largely explained by the substantial and largest increase in the number of patches (from 8 for formal trails to 160 for informal trails, +1,900%) that occurs in the Mather Gorge Zone (Table 3.8). Similarly, the largest increase in MPAR (from 0.09 for formal trails to 1.18 for informal trails, +1,211%) and the largest reduction in LPI (from 0.27 to 0.20, -26%) occurs in the same zone. The fragmentation indices and findings clearly indicate that the Mather Gorge Zone has the most substantial landscape fragmentation change associated with informal trails within GFP. However, we note that research has shown these metrics can react differently based on type of fragmentation occurring (Jaeger 2000; Moser, Jaeger et al. 2007; Jaeger, Bertiller et al. 2008). For example dissection of a patch will increase the patch count, decrease MPS, and may or may not change LPI; whereas incision doesn't affect the patch count, decreases MPS, and may or may not change LPI.

Hot Spot Analysis

The GFP trail density maps (figure 3.4) highlight what may be termed "avoidable" impacts associated with duplicative or parallel routing of multiple informal trails accessing common destinations. The regions of the park in the higher density classes are generally higher-use park areas where visitor's trampling impacts to vegetation, organic litter, and soils are most widespread and intense. When we examine GFP informal trail densities shown in Figure 3.4, we see that densities are highest in the areas adjacent to cliff tops above Mather Gorge and the Potomac River. We suspect this is largely attributable to the goal-directed behaviors of visitors desiring access to cliff-top vista sites, though other motives are possible. Closer examination of the spatial arrangement of informal trails, combined with knowledge of the formal and informal trail alignments and conditions, suspected visitor motives, and informally observed behaviors, can provide managers with greater insights to inform their decision-making.

Based on further consideration of these attributes and practices in GFP, we developed the following typology of visitor motives and behaviors that lead to off-trail traffic and informal trail creation: 1) Access - visitors leave the formal trail network to access park areas not reached by formal trails, 2) Avoidance - visitors leave formal trails due to undesirable conditions on the trail (e.g., mud, erosion, crowding/conflicts, difficult terrain), 3) Exploration - visitors are drawn off formal trails to investigate unknown areas, 4) Accidental - visitors follow an informal trail due to poor formal trail marking or inattentiveness, 5) Shortcuts – visitors leave a formal trail to reduce hiking time, 6) Attraction – visitors leave a formal trail to see, study, or photograph interesting wildlife, plants, vistas, or to investigate interesting sounds or an inviting informal trail's destination, and 7) Activities – visitors leave informal trails to engage in off-trail dependent recreational activities, e.g., orienteering and geo-caching.

It is important to note that a single informal trail is likely to develop for multiple reasons; one visitor's shortcut is potentially another's exploration. With this in mind we examined the spatial arrangement of trails within several informal trail hotspots to see what inferences could be made; Figure 3.5 illustrates several points for discussion. Notice that several trails terminate in the rocky cliff-top areas; these trails may be used to access cliff-top vistas, or for cliff and river access to engage in hiking, rock climbing, or fishing activities. These trails are also likely used for exploration, particularly when noises and glimpses of the river attract visitors. Several informal trails are aligned parallel to formal trails and the river; while these trails may be used for access, we also suspect avoidance, exploration and accidental behaviors.

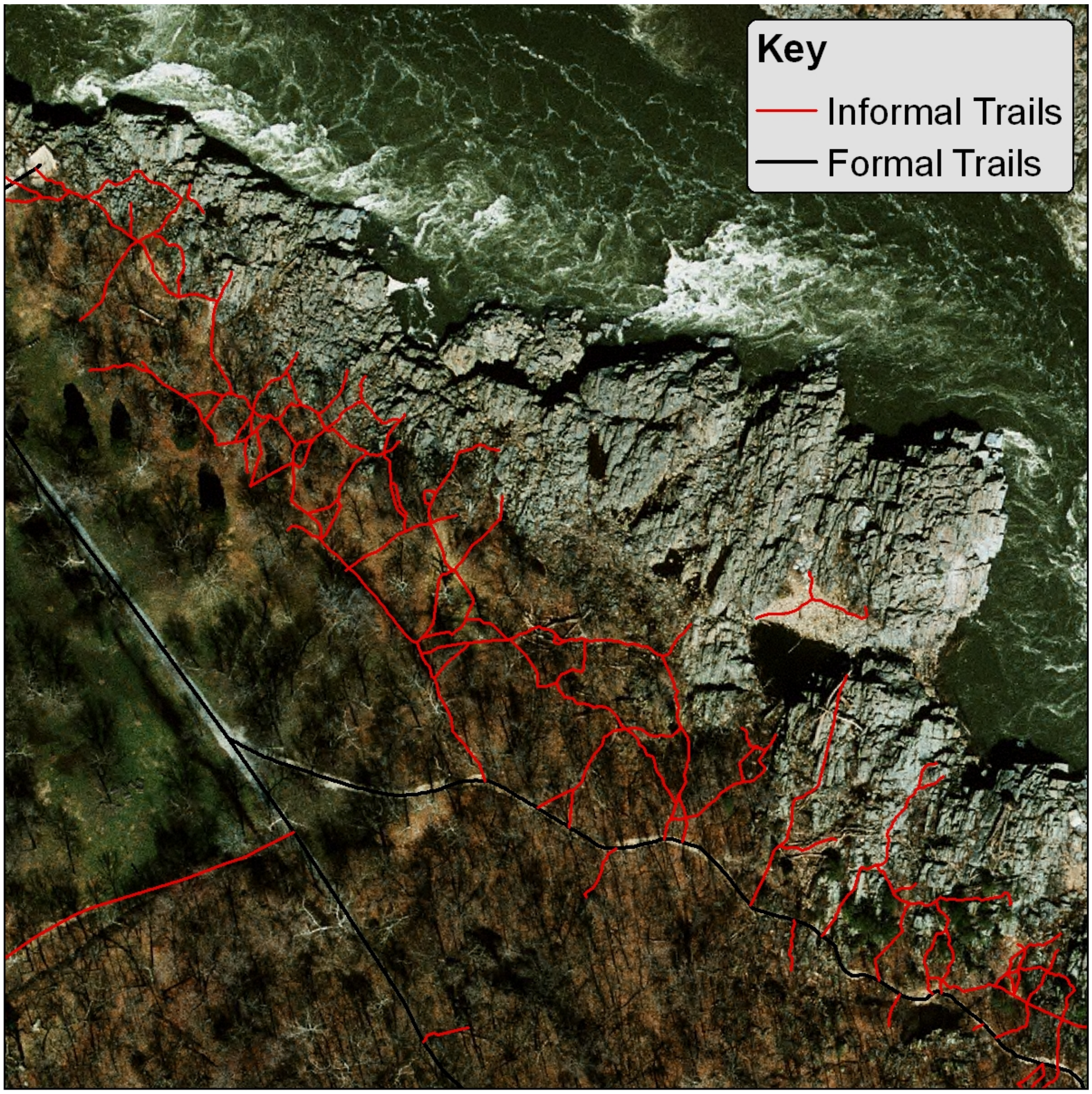

Figure 3.5 *An example of the dense network of informal trails along the cliffs adjacent to the Potomac River within GFP*

Conclusion

Protected natural area managers are frequently challenged by the development and proliferation of informal trail networks. While the occurrence of such networks can protect park resources by concentrating off-trail traffic on a limited set of trails, when extensive, substantially impacted, or located in sensitive areas, informal trail networks can unacceptably compromise resource protection objectives. This research sought to investigate and characterize the physical characteristics and topographic alignments of informal trails in an intensively visited park. Efficient methods for assessing the lineal extent and resource conditions of informal trails were developed and applied and the resulting data were analyzed to provide quantitative indicators to inform managers. The spatial distribution of informal trails was examined through analyses of park zones, landscape fragmentation indices, and trail density hot spots and mapping. When reapplied as part of a monitoring program, these assessment protocols and analytical procedures permit efficient evaluations of long-term trends and the efficacy of corrective management actions.

TG and SR are two significant trail design attributes that affect the sustainability of formal and informal trails. A census survey of GFP formal and informal trails reveals that informal trails have significantly higher trail grades and worse slope ratios than the park's formal trails. This finding suggests that visitors make poor trail designers and that visitor-created trails are less sustainable and more susceptible to subsequent degradation than formal trails, which are typically designed and maintained by trail professionals. Rapid GPS survey methods employing CC assessments by segment provided useful data for documenting informal trail distributions and conditions that were also highly correlated with trail design attributes. Several calculated metrics related to the lineal extent, areal disturbance, and spatial distribution of informal trail networks provided indicators that revealed the extent of informal trail impacts and their acceptability relative to management zoning.

Fragmentation indices calculated for GFP's informal trails provide park management with objective measures of the relative impacts associated with informal trails in each park zone. Additional analyses should examine the proximity of these trail networks and levels of landscape fragmentation to known locations of rare, threatened and endangered species and sensitive habitats within the park (which exist but were unavailable to this research). Fragmentation indices provide objective quantifiable measures to inform park management about the absolute and relative levels of impact from informal trails for different park areas at various spatial scales.

Building upon the hot spot analysis and related anecdotal discussion presented here, an objective spatial analysis of the location of high trail-density regions within the park should be conducted. Analyses may require the collection and creation of additional datasets to describe the setting within the park in a variety of ways. We suggest looking at proximity to cliffs, the Potomac River, trailheads, and a variety of park facilities (visitor center, parking lots, restrooms, etc.) and topographic variation within the park. Similar datasets (formal and informal trail censuses) from other protected natural areas will provide an opportunity to validate findings from this study. Finally, consideration of a range of visitor motives and behaviors and classifications (e.g., avoidable, unavoidable) in light of park management objectives by zone can help to inform management decision-making. Collaboration with representatives from the public, including recreation groups that are affected by informal trail management decisions, is strongly recommended.

Acknowledgements

The authors would like to thank the National Park Service for sponsoring this research and the following individuals for their assistance:

Ben Helwig, NPS, for his assistance in creating providing several GIS datasets.
Logan Park, Doctoral candidate, for his extensive field work assistance.
Laura Freeman, Virginia Tech Statistics Department, for her helpful statistical consulting.

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CHAPTER 4 CONCLUSION

Protected area managers can benefit from information derived from research that describes visitor impacts and the causal and non-causal factors that influence them. This dissertation research applied recreation ecology research methods to an investigation of factors that affect trail impacts, including a study designed to improve understanding of trail widening at Acadia National Park and a pioneering study to develop methods for assessing informal trails and impacts at Great Falls Park, George Washington Memorial Parkway. The data and knowledge gained from these studies have important implications for land managers, providing insights and guidance in the selection of effective visitor impact management strategies and tactics.

The first paper titled “The Influence of Use, Environmental and Managerial Factors on the Width of Recreational Trails” (Chapter 2) focuses on understanding the use, environmental, and managerial factors that influence trail width at Acadia National Park. The findings of this research suggest that managers can minimize trail widths (actual and width difference) by constructing side-hill trail alignments when possible. When trails cannot be aligned (or realigned) as side-hill, the findings suggest that minimizing trail grade will minimize trail width. Additionally, management actions that reduce tread roughness relative to the surrounding terrain can effectively minimize trail width; trail users will generally confine their travel to the “path of least resistance.” The data collected in this study characterize “baseline” trail conditions for comparison to future monitoring cycles, standardized protocols are provided in Appendix A for managers to reapply in future years to evaluate changes in trail conditions and to gauge the effectiveness of intervening management actions.

The second paper titled “A Spatial Exploration of Informal Trail Networks within Great Falls Park, VA” (Chapter 3) examines the informal and formal trails within Great Falls Park, VA. Findings from this study indicate that informal trails have less sustainable design attributes than formal trails: Informal trails are more closely aligned to the fall line and are steeper than formal trails. Computation of fragmentation indices using the informal trails GIS layer aid in quantifying potential resource impacts associated with informal trail networks, and highlight potential mismatches between park management goals and current conditions within park management zones. Hotspot analyses illuminate areas within the park with high informal trail densities and areal extents of impact. Anecdotal evaluation of the highest density regions provide some insights and suggests the need for future research and spatial analysis to further understand how visitor motives, use, environmental, and managerial factors interact on the landscape and influence the presence/creation of informal trails.

The two papers presented within this dissertation examined the problems of trail widening and informal trails associated with recreational use within protected natural areas. Managers of protected natural areas are tasked with the difficult goal of providing natural resource conservation/protection while allowing for visitation and access to the public. This task is not a simple one: the interaction of visitors and natural resources within protected natural areas is a very complex and dynamic system; management of these systems must be flexible and cognizant of spatial and temporal variations within the system. The results of the analyses from the above two papers provide scientifically-grounded data and perspectives that can aid managers in making better informed decisions. These perspectives are not complete and future research can build upon the collective body of trail related research to improve trails and trail management within protected natural areas.

While this research strived to be complete and universal, we must point out some shortcomings. There are several unique characteristics of the terrain and trails at Acadia National Park that limit the depth and breadth of applicability of the implications of the trail width research. Acadia's trails had very little mud (1 trail section ~0.5km long and a few very localized). Additionally, the mountain ridges in Acadia have very thin soils and vast expanses of naturally exposed (glaciated) bedrock; this made it impossible to assess trail width for part of the park (8% of points, 91 out of 1118 sample location). The use level data created by the park were not empirically based; trail managers and rangers collaborated to assign categorical use levels to each trail segment. Use level estimates from trail counters, or observational counts provide a quantitative means of assessing use level and should be used in future research.

The Potomac Gorge also has several unique attributes that are important to be aware of when looking to apply findings from this park elsewhere. This park is is nestled into a densely populated suburban/urban area and sees very high use by both locals and tourist populations. The visitation patterns found here are likely very different from a larger more remotely located park such as Yellowstone or Grand Teton. Our informal trail width data was based on "mental averaging" of each segment collected; we suspect that there is more error inherent in this method than the formal trail's transect procedures. Future research should look at alternative methods of collecting trail width data for informal trails, and incorporate additional measures of trail condition such as maximum incision, or cross sectional area. Comparing the widths of these two classes of trails within GFP is further complicated because many of the formal trails are maintained to very wide (3m+) widths to accommodate vehicular access and high use. Finally, while our research focused primarily on physical assessment of trails, we suggest that coupling the findings with social science and visitor observation and survey work will give a more complete understanding of these problems and lead to better informed and effective management decisions.

Future trail impact research should continue to target specific managerial problems and examine trail design, construction and maintenance techniques that sustain appropriate types and amounts of traffic while minimizing adverse ecological impacts. The body of knowledge regarding trails is very diverse and resides in trail users, trail professionals, planners, scientists, and public land managers; each of these groups provides an essential but different perspective and approach to trail management. Expansion of the collective knowledge and expertise will be efficiently accomplished if cooperation and sharing between these groups can be realized. I look forward to being a part of this cooperative learning and seeing the continued development, management, and enjoyment of trails by all types of user groups in the coming decades.

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APPENDIX A

Acadia National Park: Monitoring Manual for Formal Trails

(*version 06/16/09*)

This manual describes standardized procedures for conducting an assessment of resource conditions on formal (designated) recreation trails within Acadia National Park. The principal objective of these procedures is to document and monitor changes in trail conditions following construction. Their design relies on a sampling approach to characterize trail conditions from measurements taken at transects located every 500 feet along all trail segments. Points are placed in the ArcMAP 9.2 GIS software utilizing a macro called "pointsalongpoly". 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. 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
(Check before leaving for the field)

- ☐ This manual on waterproof paper
- ☐ Topographic and driving maps
- ☐ Pencils
- ☐ Tape measure in inches (6 ft)
- ☐ Metal paper binder clips (2) to attach tape to trail border stakes
- ☐ Trimble GPS
- ☐ Compass
- ☐ Tape measure in tenths of feet (20 ft)
- ☐ Tent stakes (3)
- ☐ Clinometer

Point Sampling Procedures

Consult paper maps to preplan your daily routes for collection. After determining your route, navigate to the first trail sample point using the Trimble GPS. When the proximity alarm sounds, verify the distance to the sample point is < 5m. Place the transect across the trail at the location of your front foot. Collect transect data using the ACAD FT data dictionary, and the excel spreadsheet loaded on the Trimble GPS.

General Trail Information (collected in data dictionary)

1. **Transect Number:** This field will automatically increment for you. You will use this field's value as a input in the Excel Mobile spreadsheet used to collect CSA (see #16)
2. **Trail Width (TW):** From the sample point, extend a line transect in both directions perpendicular to the trail tread. Identify the endpoints of this trail tread transect as the most pronounced outer boundary of visually obvious human disturbance created by trail use (not trail maintenance like vegetation clearing). These boundaries are defined as pronounced trampling-related changes in ground vegetation height (trampled vs. untrampled), cover, composition, or, when vegetation cover is reduced or absent, changes in organic litter (intact vs. pulverized) (see photo illustrations in Figure 1). The objective is to define the trail tread that receives the majority (>95%) of traffic, selecting the most visually obvious outer boundary that can be most consistently identified by you and future trail surveyors. Include any secondary parallel treads within the transect only when they are not differentiated from the main tread by strips of less disturbed (taller) vegetation or organic litter.

   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 obstruct 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).
3. **Secondary Treads (ST):** Count the number of trails, regardless of their length, that closely parallel the main tread at the sample point. *Do not count the main tread.*
4. **Trail Azimuth (TA):** 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).
5. **Trail Grade (TG):** The two field staff should position themselves on the trail 5 ft either side of the transect. A clinometer is used to determine the grade (% slope) by sighting and aligning the horizontal line inside the clinometer with a spot on the opposite person at the same height as the first person's eyes. Note the percent grade (right-side scale in clinometer viewfinder) and record (indicate units used). Note: if conducted by one person then place clinometer on a clipboard with the window facing you. Orient the clipboard to be parallel to the trail grade and record degrees off the visible scale in the window. After data entry convert to percent slope = [tan (degrees)] x 100.

6. **Fall Line Azimuth (FA):** Face directly upslope, take and record another compass azimuth - this is the aspect of the local landform.
7. **Landform Grade (LG):** Assess an approximate measure of the prevailing landform slope in the vicinity of the sample point. Follow the one-person procedure described in #6.
8. **Landform Position (LFP):** Record whether the tread at the sample point was assessed as a direct ascent or side-hill constructed trail
9. **through 15. Trail cover classes:** 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%**.

Bare 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.
Organic Litter:	Surface organic matter including intact or partially pulverized leaves, needles, or twigs that mostly or entirely cover the tread substrate.
Vegetation:	Live vegetative cover including herbs, grasses, mosses rooted within the tread boundaries. Ignore vegetation hanging in from the sides.
Natural Rock:	Naturally-occurring rock (bedrock, boulders, rocks, cobble, or natural gravel). If rock or native gravel is embedded in the tread soil estimate the percentage of each and record separately.
Stone Work:	Native or imported stone that has been placed to create a tread surface. This class includes steps, pavers, etc.
Gravel:	Human-placed (imported) gravel.
Roots:	Exposed tree or shrub roots.
Man Made:	Human-placed material (excluding gravel): wood, geotextile, pavement etc (water bars, bog bridging, cribbing).

16. **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.

CSA Measurement Procedure: In the CSA spreadsheet (Microsoft excel mobile on Trimble GPS), label a new row with the GPS file name and point ID for the transect. Place the transect stakes as described under the appropriate situation (a-d below). In the next column define the CSA width interval used for this transect (either 0.3 or 1.0 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). Starting in the next column, 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). 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 in the data sheet using as many columns as needed for the TW. 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.

a) <u>Direct-ascent trails, recent erosion</u>: 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) <u>Direct-ascent trails w/historic erosion</u>: 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) <u>Side-hill trail</u>: 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.

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.

17. Photo ID: Take a digital photo of the transect with the stakes and measuring tape in place. Attempt to capture a photo that will aid in relocating the transect in the future; this involves framing the photo so that it includes durable "landmarks" (trees, roots, unique rocks etc). Record the photo ID in this

Collect all equipment and move on to the next sample point: Select the next point as a navigation target and hike along your route towards the point. Watch the distance to target so you can be prepared to stop at your target; when the proximity alarm sounds, confirm that you are <5m from the point and place the transect across the trail at the location of your front foot.

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.

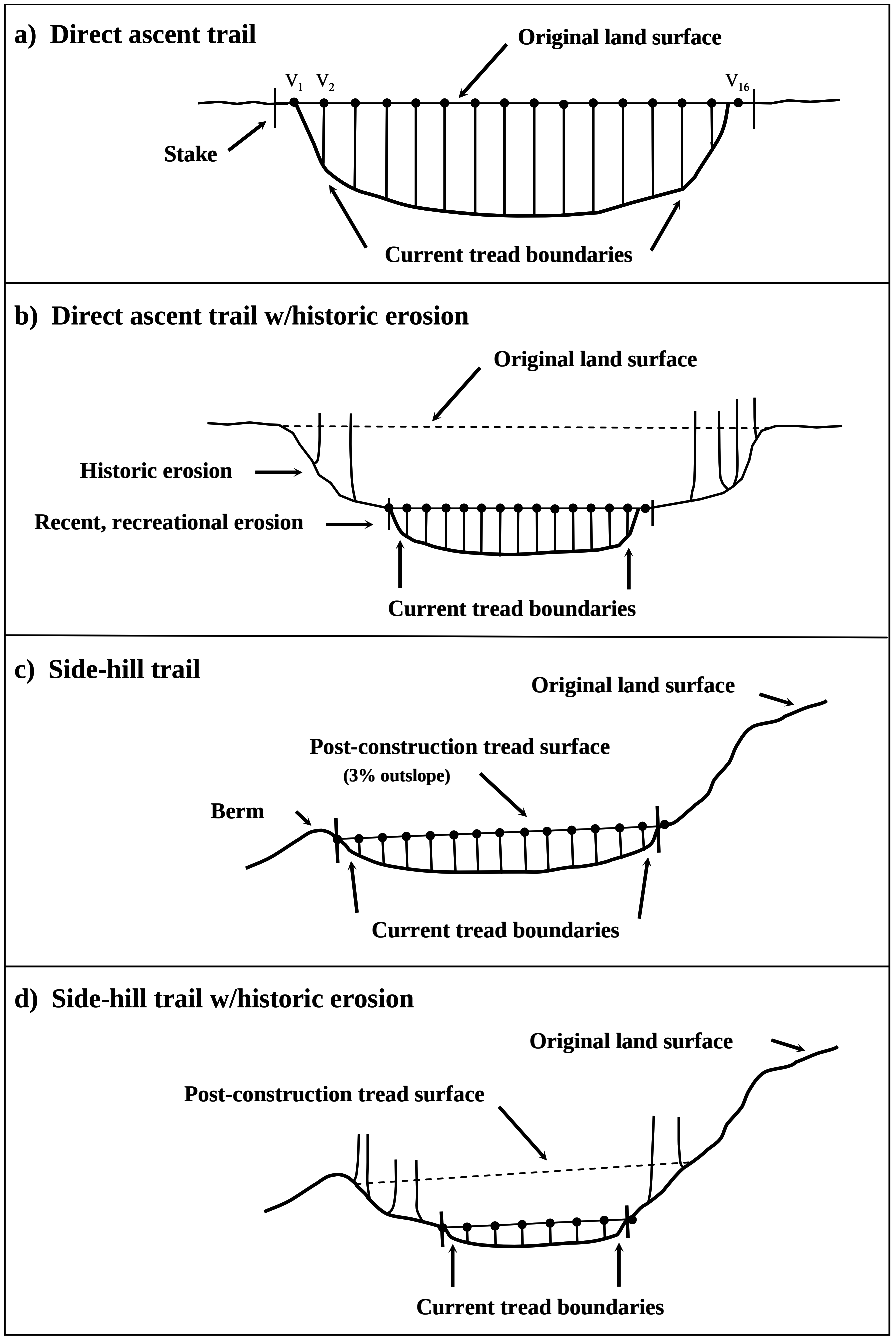

Figure 2. Cross sectional area (CSA) diagrams illustrating alternative measurement procedures for direct ascent trail alignments (a & b) vs. side-hill trail alignments (c & d) and for relatively recent erosion (a & c) vs. historic erosion (b & d).

APPENDIX B

Great Falls Parks: Monitoring Manual for Formal Trails

(*version 4/25/07*)

This manual describes standardized procedures for conducting an assessment of resource conditions on formal (designated) recreation trails within Great Falls and C&O Parks. 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 300 feet along randomly selected trail segments. Distances are measured with a measuring wheel. Measurements are conducted at sample points to document the trail's width, depth, substrate, slope, alignment and other characteristics. These procedures take approximately three minutes to apply at each sample point. Data is summarized through statistical analyses to characterize resource conditions for each trail segment and for the entire trail system. During future assessments it is not necessary to relocate the same sample points for repeat measures. Survey work should be conducted during the middle or end of the primary use season. Subsequent surveys should be conducted at approximately the same time of year.

Materials
(Check before leaving for the field)

- ☐ This manual on waterproof paper
- ☐ Topographic and driving maps
- ☐ Pencils
- ☐ Tape measure in inches (6 ft)
- ☐ Metal paper binder clips (2) to attach tape to trail border stakes
- ☐ Trimble GPS
- ☐ 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.

General Trail Information

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

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

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

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

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

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

Starting/Ending Point: Record a brief description of the starting and ending point of the trail survey. Try to choose identifiable locations like 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 300. Record this number on the first row of the form. This will be the first sample point, from which all subsequent sample points will be located in 300 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 300 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 300 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 300 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) **Trail Type (TT):** Record whether the tread at the sample point was assessed as a direct ascent or side-hill constructed trail (see definitions in #11). Record the letter code in the TT column.
   DA – Direct ascent (fall-line), **SH** – Side-hill trail

9) **Erosion Type (ET):** Record whether soil erosion at the sample point, if present, appears to be recent or historic (see definitions in #11). Record the letter code in the ET column.
   RE – Recent erosion, **HE** – Historic erosion

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

11 **Landform Grade (LG):** Assess an approximate measure of the prevailing landform slope in the vicinity of the sample point. Follow the one-person procedure described in #7.

12) **Trail Slope Alignment Angle (TSA):** Assess the trail's alignment angle to the prevailing land-form in the vicinity of the sample point. Position yourself about 5 ft downhill along the trail from the transect and sight a compass along the trail to a point about 5ft past the transect; record the compass azimuth (0-360, not corrected for declination) on the left side of the column. Next face directly upslope, 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).

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

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

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).

15) **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 within the tread boundaries. See Figure 2, noting differences in MIC measures for side-hill vs. non-side-hill trails.

16) **Modal Incision, Current Tread (MOD):** Record what you judge to be the "most typical" or "modal" incision measure for the entire transect. This measure will be used to compare against "actual" modal incision measures from # 16 to evaluate the accuracy of such judgments for use in new rapid assessment tread erosion procedures currently under development.

17) **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) – <u>if alternative intervals are used *note the interval value* on the CSA form</u>. 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 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.

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”**

e) Side-hill trail with historic erosion: 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.

18-27) **Tread Condition Characteristics:** Along the trail tread width transect, estimate to the nearest 10% (5% where necessary) the aggregate lineal length occupied by any of the mutually exclusive tread surface categories listed below. **Be sure that your estimates sum to 100%**.

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

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

Problem Assessment Procedures

28) **Informal Trails (IT):** Record the trail distance form the measuring wheel for each informal (visitor-created) trail that intersects the survey trail segment. This indicator is intended to

provide an approximation of the extensiveness of unofficial, visitor-created trails associated with survey trail. Do not count formal trails, roads of any type, extremely faint trails with untrampled vegetation in their treads, trails <10 ft long, or trails that have been effectively blocked off by managers. Informal trails are trails that visitors have created to access features such as streams, scenic attraction sites1, cliffs, vistas, cultural sites, or to cut switchbacks, avoid mud-holes, rutted treads, steep obstacles, or downed trees, or that simply parallel the main trail. Count both ends of any informal trails ≥10 feet long that loop out and return to or parallel the survey trail. Include any distinct animal or game trails as these are generally indistinguishable from human trails and their true origin is likely unknown.

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

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

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

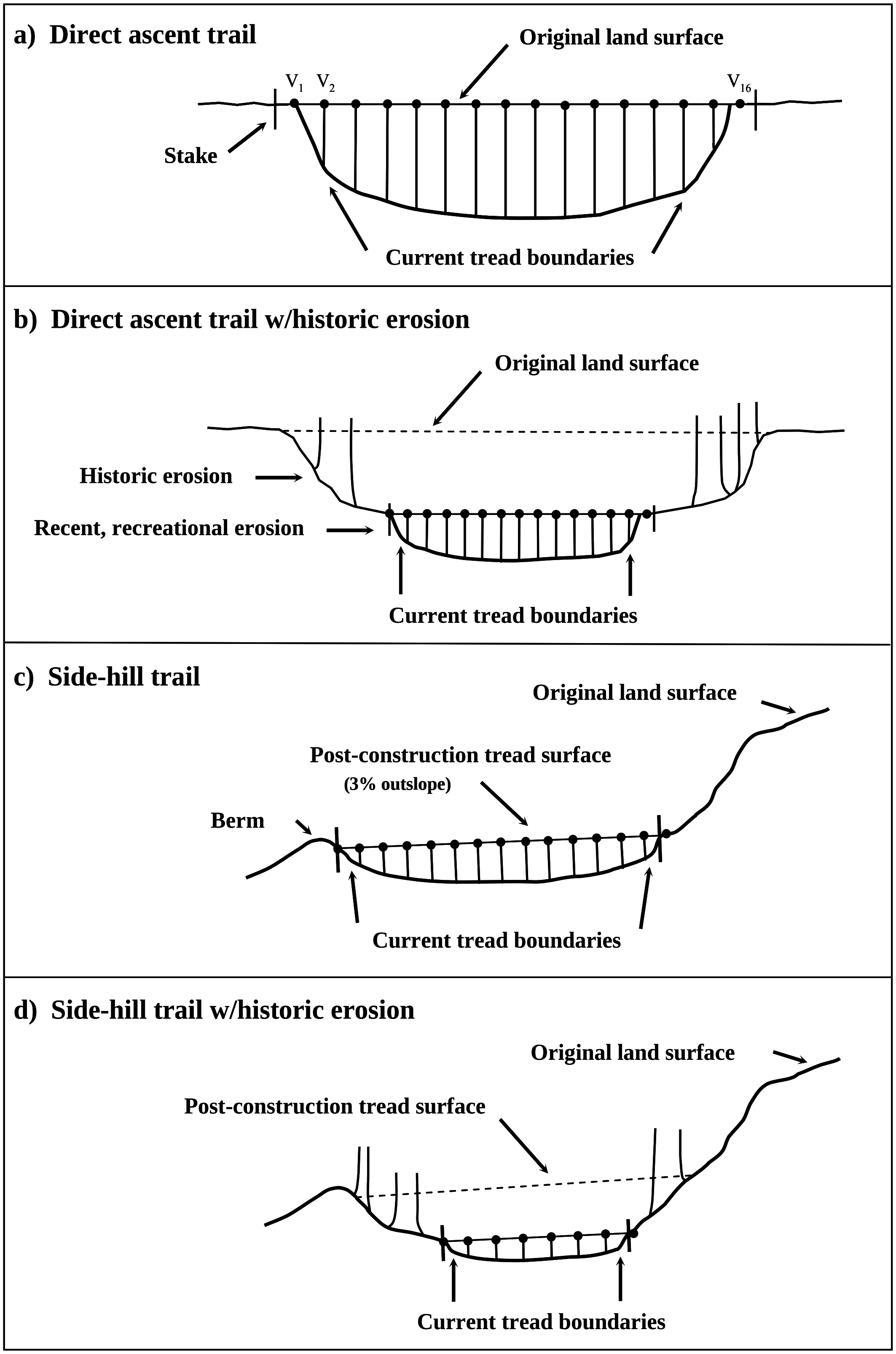

Figure 2. Cross sectional area (CSA) diagrams illustrating alternative measurement procedures for direct ascent trail alignments (a & b) vs. side-hill trail alignments (c & d) and for relatively recent erosion (a & c) vs. historic erosion (b & d).

Point Sampling Form

Trail Segment Code _________ Trail Name ____ Surveyors____________________

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

Starting Point: **UTM:______________________________**

Ending Point: **UTM:____________________________________**

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

Dist = Wheel Distance **TSA = Alignment (Trail° / Landform°)** **S = Soil** **G = Gravel**
TT = Trail Type (DA, SH) **ST = Secondary Treads** **L = Litter** **RT = Roots**
ET = Erosion Type (RE, HE)form) **TW = Tread Width** **V = Vegetation** **W = Water**
TG = Trail Grade **MIC = Max. Incision** **R = Rock** **WO = Wood, human-placed**
LG = Landform Grade **CSA (calculated from data)** **M = Mud** **O = Other (Specify)**

Problem Assessment and Cross Sectional Area Form

Trail Segment Code ________ **Trail Name** ______________________________

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

Great Falls Parks: Informal Trail Data Collection Protocols

C&O Canal National Historic Park and the George Washington Memorial Parkway

Developed by Jeff Marion, Jeremy Wimpey, and Logan Park
Virginia Tech/Dept. of Forestry, Blacksburg, VA
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, Virginia Tech, Department of Forestry, 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 assist 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

1 – Trail distinguishable; slight loss of vegetation cover and/or minimal disturbance of organic litter
2 – Trail obvious; vegetation cover lost and/or organic litter pulverized in center of tread in most places
3 – Vegetation cover and organic litter lost across the majority of the tread
4 – Soil erosion in the tread beginning in some places

5 – Soil erosion is common along the tread

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

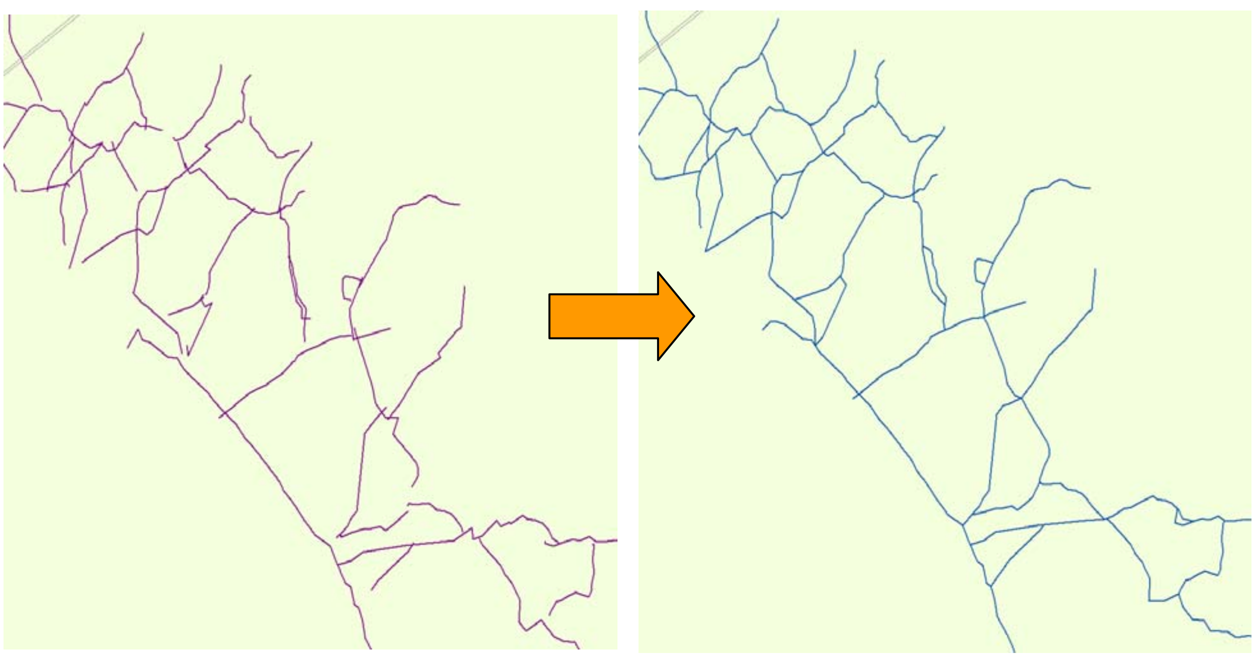
Data should be post processed (differentially corrected and converted to GIS appropriate format(s) using GPS software (we used Trimble's Pathfinder Office and converted to ArcMAP Shapefiles) by park staff familiar with GIS/GPS)

The output files should be merged into one singular file representing the Informal trail network

This data will likely need editing due to the nature of GPS data collection

GIS Staff should edit this data to more accurately represent 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
    - The anchor points layer is great for establishing a junction location
- 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: Editing of shapefiles in ArcMAP leads to the creation of more accurate trail network representation. Editing relies on field staff knowledge, satellite imagery, and other trail features to refine the network.

Informal Trail Data Dictionary

InformalTrail:

LineFeature

Label1=AverageWidth

ConditionClass:Menu;Normal,Normal

1 2 3 4 5 Other

AverageWidth=Numeric, DecimalPlaces=0

Minimum=1,Maximum=144,DefaultValue=8 Normal,Normal

Segment#:

Numeric,DecimalPlaces=0

Minimum=0,Maximum=500, DefaultValue=1,StepValue=1 Normal,Normal

Comment:

Text,MaximumLength=30 Normal,Normal

ITAnchorPoint:

Feature

Label1=Number

Label2=Comment

Number=Numeric DecimalPlaces=0

Minimum=0,Maximum=500,DefaultValue=1,StepValue=1 Normal,Normal

Comment:

Text, MaximumLength=30 Normal,Normal