Monitoring Trail Conditions: New Methodological Considerations

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Introduction

The U.S. National Park Service (NPS) accommodates nearly 300 million visitors per year, visitation that has the potential to produce negative effects on fragile natural and cultural resources. The policy guidance from the NPS *Management Policies* recognizes the legitimacy of providing opportunities for public enjoyment of parks while acknowledging the need for managers to "seek ways to avoid, or to minimize to the greatest degree practicable, adverse impacts on park resources and values" (NPS 2001). Thus, relative to visitor use, park managers must evaluate the types and extents of resource impacts associated with recreational activities, and determine to what extent they are unacceptable and constitute impairment. Visitor impact monitoring programs can assist managers in making objective evaluations of impact acceptability and impairment and in selecting effective impact management practices by providing quantitative documentation of the types and extent of recreation-related impacts on natural resources. Monitoring programs are explicitly authorized in Section 4.1 of the *Management Policies:*

> Natural systems in the national park system, and the human influences upon them, will be monitored to detect change. The Service will use the results of monitoring and research to understand the detected change and to develop appropriate management actions.

Visitor impact monitoring is also an integral component of evaluating carrying capacity, which is defined under the NPS Visitor Experience and Resource Protection (VERP) framework (Manning et al. 1995; NPS 1997) as the type and level of visitor use a park can accommodate while sustaining resource and social conditions that complement the purposes of the park and its management objectives. The VERP framework specifies desired resource and social conditions and incorporates indicators and standards of quality that quantify impact acceptability and impairment. Visitor impact monitoring is an essential component for periodic evaluations of current conditions to compare against standards or to evaluate the success of management actions. Visitor impact monitoring is also a component of the NPS Vital Signs Monitoring Program, which seeks to monitor selected biophysical indicators that represent the health or condition of park natural resources. Visitor use is frequently a primary "agent of change" affecting park vegetation, soil, wildlife and water resources.

This paper aims to highlight selected examples of current research on addressing methodological challenges associated with the development of trail assessment and monitoring procedures as applied to formal and informal trails. The discussion is by no means a representation of all important issues; rather, it reflects the major challenges faced in recent visitor impact studies in which the authors were involved.

Trail impacts and monitoring methods

One activity that virtually every park visitor engages in is walking on trails. Even light traffic can remove protective layers of vegetation cover and organic litter from formal or informal "visitor-created" trails (Cole 2004). Trampling can alter the appearance and composition of trailside vegetation by reducing vegetation height and favoring trampling-resistant species (Cole 1995). Visitors and livestock can introduce and transport non-native plant species along trail corridors, some of which may out-compete undisturbed native vegetation and migrate away from trails (Tyser and Worley 1992). Visitor traffic can also compact soils, widen trails, exacerbate problems with muddiness, and accelerate soil erosion (Leung and Marion 2000). Soil erosion, unlike most other forms of trail impact, is critical because it is not self-limiting. For example, soil loss on 328 mi of surveyed trails in Great Smoky Mountains National Park exceeded 1 ft below the estimated post-construction tread surface at 734 locations (14.6 mi; 4.5%), and exceeded 2 ft at 100 locations (2.51 mi; 1.1%) (Marion 1994).

Trail impact assessments and monitoring seek to describe resource conditions and impacts for the purpose of documenting trends in trail conditions, investigating relationships with influential factors, and evaluating current conditions in light of management standards of quality or the efficacy of corrective actions. A variety of assessment and monitoring methods have been developed for formal trails and are described in the literature, as reviewed and compared by Cole (1983) and Leung and Marion (2000). These methods may be classified into two main groups based on monitoring approaches (Leung and Marion 2000). *Sampling-based* approaches employ either systematic point sampling, where tread assessments are conducted at a fixed interval along a trail (Cole 1983, 1991), or by stratified point sampling, where sampling varies in accordance with various strata such as level of use or vegetation type (Hall and Kuss 1989). Alternately, *census-based* approaches employ either sectional evaluations, where a trail is divided into sections with assessments made for each section (Bratton et al. 1979), or problem census evaluations, where continuous assessments record every occurrence of predefined impact problems (Cole 1983; Marion 1994; Leung and Marion 1999a). More elaborate and time-consuming methods for accurately characterizing soil loss (Leonard and Whitney 1977) and vegetation changes (Hall and Kuss 1989) have also been developed.

Relatively less attention has been paid to assessing and monitoring informal visitor-created trails (often also referred to as "social trails"). Most previous monitoring studies on informal trails have focused on their proliferation in the park landscape rather than resource conditions or tread conditions. Three main monitoring approaches have been developed specifically for informal trails. Some past visitor impact studies had informal trails included as an indicator, with the level of proliferation assessed by tallying the occurrence of informal trail segments extending from formal trail networks or recreation sites (Marion 1994; Leung et al. 2002). Alternatively, the entire social trail network of a park or selected portions of a park can be inventoried and mapped (Cole et al. 1997; Leung et al. 2002). Most of these studies have also incorporated condition-class ratings to the assessments. Finally, very few studies have actually monitored social trail networks more than one time to enable a temporal evaluation (Yosemite National Park 2005). Due to the extensive nature of some informal trail networks, the efficiency of field assessments is a particular concern. The advent of geospatial techniques seems to provide potential solutions to this challenge, though such technologies benefit monitoring of formal trails as well.

Sampling-based or census-based?

Given the diverse array of trail condition assessment methods, an important consideration is selection between a sampling-based or census-based approach. In contrast to many other forms of monitoring, a sampling method may not necessarily confer a substantial savings in assessment time as most methods require hiking all or nearly all of the selected trails. For example, two leading methods, systematic point sampling and problem census, each require surveyors to hike the entire trail, but trails in good condition would require fewer stops to document trail impacts so the problem census method would be more efficient. Marion and Leung (2001) evaluated both methods on a common segment of the Appalachian Trail in Great Smoky Mountains National Park. They concluded that the point sampling method provides more accurate and precise measures of trail characteristics that are continuous (e.g., width or depth) or frequent (e.g., exposed soil). The problem census method is a preferred approach for monitoring trail characteristics that can be easily defined (e.g., excessive erosion) or are infrequent, particularly when information on the location and lineal extent of specific trail impact problems is needed. However, measurements for this method sometimes require judgments that may be subjective regarding where the impact problems begin and end (e.g., where excessive muddiness or erosion $\geq$ 6 in begins and ends).

Condition classes

Condition-class systems are commonly used in visitor impact monitoring (Leung and Marion 2000). Until recently, applications of such systems were largely restricted to parks in North America and Australia/New Zealand. The third author developed a set of four qualitative trail condition classes (Table 1) and applied them to 55 mi of high-use tourist trails in Sagarmatha (Mount Everest) National Park, Nepal (Nepal 2003). The descriptive statements employed in defining the condition classes were based on findings from prior application of several measurement-based trail degradation procedures. Results indicated that there were 69 Class I segments (7.7 mi total), 58 Class II segments (6.2 mi), 16 Class III segments (2.1 mi), and 65 Class IV segments (7.2 mi). The remaining 32 miles of trails did not exhibit any degradation so no condition class was applied there. A principal advantage of this method is its ease of application and simplicity in presenting the findings. However, judgments involved in distinguishing between the classes introduce subjectivity, and,

Table 1. Qualitative trail condition classes.

Condition class	Description
Class I	**Lightly damaged trail.** Either one or a combination of several impact features is present. Trail width is < 5 ft; no more than three treads apparent; low to moderate potential for trail expansion; some muddy spots may be present; incision is < 0.5 ft; some exposed and loose soil may be present on the trail surface. Overall, a trail under this classification is stable and does not require any maintenance as long as the conditions do not deteriorate further.
Class II	**Moderately damaged trail.** Trail segments clearly show deteriorating conditions. Either a single impact feature with significant damage, or a combination of more than two impact features is present: trail is wider than 5 ft; incision between 0.5 and 1.0 ft (incision of 1.5 ft in the absence of any other features will satisfy the condition itself); more than three treads are present; muddiness and running water on trail; trail is displaced; and soil is unconsolidated. The degree and magnitude of trail damage is significant enough to prescribe some management actions.
Class III	**Highly damaged trail.** This is a potential hotspot, showing either one type of impact feature or a combination of several features. Both the magnitude and the extent of damage are significant. Basic impact features include trail width, multiple treads and incision. Usually these are present in combined forms, for example, trail braiding leading to excessive width. In certain cases, trail width is less but several treads are present, some of which are deeply incised (> 1.5 ft). Frequently exposed bedrock and roots are present in addition to other impact features. A trail affected by landslides or localized slope failures also qualifies as a highly damaged trail.
Class IV	**Severely damaged trail or "hotspot."** Either a single criterion or a combination of several impact features qualifies this category. The basic parameters are trail width, multiple treads, and trail incision, and are significantly damaged in extent and magnitude compared with Class III. Other impact features being satisfactory, if the basic parameters show heavy damage, it is considered as severely damaged. A trail under this classification exhibits excessive width (> 10 ft), multiple treads (> 5), and incision > 1.5 ft. It may also exhibit signs of downhill sliding. Soil on the trail surface is unconsolidated, and no organic layer is present; exposed bedrock is frequent; trailside is highly eroded; root exposure is excessive; trail is very muddy requiring circumvention; trail outslope is > 10%. Overall, a trail under this classification requires urgent repair, without which land degradation is inevitable in the near future. Damage is likely to spread out both vertically (depth) as well as horizontally.

because class definitions can employ several forms of trail degradation, interpretation of the findings can be difficult.

Monitoring vegetation changes along trails

Assessing vegetation changes, including changes in vegetation cover and composition, is a growing concern, particularly as they relate to the introduction and spread of non-native plants. Two factors make this work more challenging, however: (1) the lack of availability of field staff with plant identification skills, and (2) the large amount of time required to perform plant sampling methods along with identification and cover estimation. Nepal and Way (in press) experimented with a permanent transect survey with quadrat sampling of trailside vegetation along two trails in Mount Robson Provincial Park, Canada. Employing systematic sampling with a random start, transects were located every 1,320 ft along the trails with a 3.3x3.3-ft trailside quadrat established perpendicularly to the trail border, with another "control" quadrat established 19.3 ft off-trail. Both quadrats were placed along the extended trail transect line, which was georeferenced with a global positioning system (GPS) and marked by tagging the closest mature tree.

Plants within each quadrat were identified to the species level where possible and assessed for cover to enable subsequent analyses of differences in relative cover, species richness and dissimilarity, and the presence and cover of non-native species. Comparisons of plants found in the trailside and control quadrats also permit evaluations of how differences in morphological characteristics can affect a plant's resistance to trampling damage, as well as enabling classification of plants relative to the trailside disturbance regime (increasers and decreasers).

Monitoring soil erosion

Soil erosion along trails is perhaps the most significant form of trail degradation (Figure 1). Ecologically, soil loss from trails could be considered a significant "irreversible" form of impact since most of the soil is transported off trail treads where it cannot be retrieved and replaced. The eroded soils may smoothen adjacent ground vegetation, or enter water bodies where it can remain suspended or settle out on rock or gravel substrates and harm aquatic life. The resulting rutted trails then intercept and transport greater volumes of water, accelerating further soil erosion and altering natural patterns of water runoff. Even in the absence of further use, the loss of organic litter and topsoil and exposure of roots and rocks can greatly retard the natural recovery of vegetation. From a visitor's perspective, eroded treads are more difficult and potentially unsafe to use and they are aesthetically displeasing (Figure 2). These issues also have substantial significance given the important role played by trails as a transportation network and the substantial time visitors spend on trails in backcountry environments.

Unfortunately, obtaining accurate, precise, and efficient measures of soil erosion along trails is perhaps the most challenging of all trail condition assessments. Scientists have developed and refined numerous methods for assessing soil erosion along trails. These methods include qualitative condition-class assessments, proxy rapid assessment measures (e.g., maximum incision measures), and several variations of methods that measure the cross-sectional area of trail ruts. Other methods include a

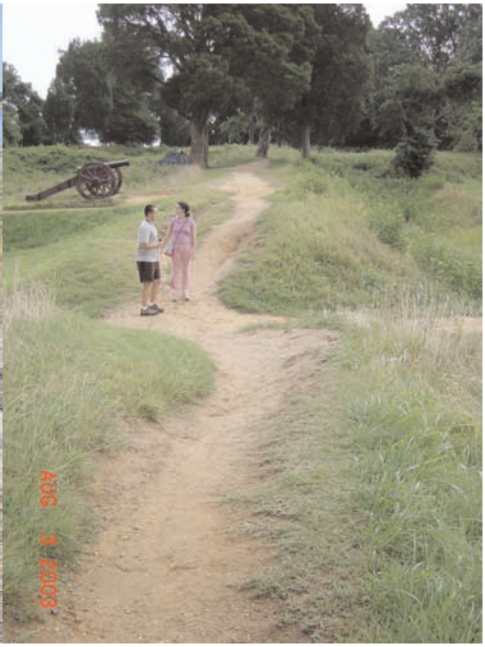


Figure 1 (left). Trail erosion at Assategue Island National Seashore. Photo courtesy of Yu-Fai Leung.
Figure 2 (right). Eroded trails, such as these among historic earthworks at Colonial National Historical Park, are aesthetically displeasing to many people. Photo courtesy of Yu-Fai Leung.

performing a census of severely eroded or actively eroding segments, and taking stereo photography. Leung and Marion (2000) and Cole (1983) provide more comprehensive reviews of trail impact monitoring methods, with citations.

This section provides a review of recent advances in direct measurements of soil erosion on trails, specifically the maximum incision and cross-sectional area methods. Soil erosion measurements have generally been applied at sample points located at fixed intervals along a trail, typically with a randomized start to ensure that any point along a trail has the potential to be assessed. Selecting an appropriate sampling interval has been an arbitrary process and intervals reported in the literature have ranged from 150 ft to 1,650 ft (Cole 1983). Leung and Marion (1999b) examined the influence of sampling interval on the accuracy of estimates for four trail impact indicators, including tread incision. Their research provides guidance for selecting a sampling interval, revealing that an interval up to 325 ft yields an excellent level of estimate accuracy for the lineal extent of these impact indicators, with intervals of up to 1,650 ft acceptable when greater efficiency is needed.

Trail maximum incision measures are taken at each trail sample point from a line transect established perpendicularly to the trail tread to the lowest point on the trail tread. A perennial problem that affects both the accuracy and precision (reliability) of trail incision measures are differing determinations of the appropriate upper datum to measure to. The principal goal of soil erosion measures on trails is to assess only post-construction soil loss that is related to recreational uses. This is generally a straightforward process for trails in flat terrain (Figure 3a). Such trails are generally "walked in" or involve minimal removal of organic layers. However, one problem that can lead to possible measurement errors and erroneous data is when a recreational trail follows a former primitive road alignment where substantial soil loss is evident from either initial construction (often with heavy machinery) or historic erosion that predates recreational uses (Figure 3b). While many studies have employed maximum incision measures, few have specified how these measures were taken and none appear to have addressed this particular problem. In response, Farrell and Marion (2002) developed and applied two maximum incision measures:

1. *Maximum incision, post-construction* (MIP): the maximum incision of the trail tread along a transect established perpendicularly to the trail at the sampling point, from the original land surface to the lowest substrate surface.
2. *Maximum incision, current tread* (MIC): the maximum incision of the trail tread along a transect established perpendicularly to the trail at the sampling point, from a line stretched between stakes placed at the current trail boundaries to the lowest substrate surface.

When applied to trails in flatter terrain, both measures assume no construction-related soil loss. MIP measures are more time-consuming on trails with substantial amounts of historic soil erosion (Figure 3b). For example, our experience in national parks has found trails with MIP measures of over 8 ft, often with 20- to 30-year-old trees growing from the eroded trailsides. It is difficult to take accurate maximum incision measures in such situations, and including historic erosion that is not recreation-related is counter to the principal goal of monitoring. When historic erosion is evident, we suggest that the MIC measure provides a more accurate and efficient assessment of on-going recreation-related erosion and is a more managerially relevant indicator.

The application and subsequent interpretation of maximum incision measures becomes more challenging for trails located in steeper terrain that required side-hill construction techniques (Figure 3d). Side-hill trails are constructed by excavating soil and moving it down slope to create a gently out-sloped trail tread. Measuring recreation-related soil loss on these trails requires an estimation of the upper datum to measure to—the post-construction tread surface. Differing determinations of this datum can again introduce considerable measurement error. Published trail soil erosion assessment methods suggest that previous studies may have ignored this dilemma as well. Farrell and Marion (2002) also developed procedures and diagrams (Figure 3d–f) for side-hill trails, including situations where trails follow old primitive roads with substantial amounts of historic erosion. This guidance directs field staff to estimate the post-construction tread surface through examination of local features, including tree roots, rocks, and trail edges in the vicinity of transects, and a 3% outslope of the post-construction tread. Most agency guidance calls for a 5% outslope, so these procedures provide a somewhat conservative estimate of soil loss. Guidance on when to ignore the presence of berms (Figure 3e–f) comprising soil and organic litter along the lower trail edge is also included, as berms grow in height over time.

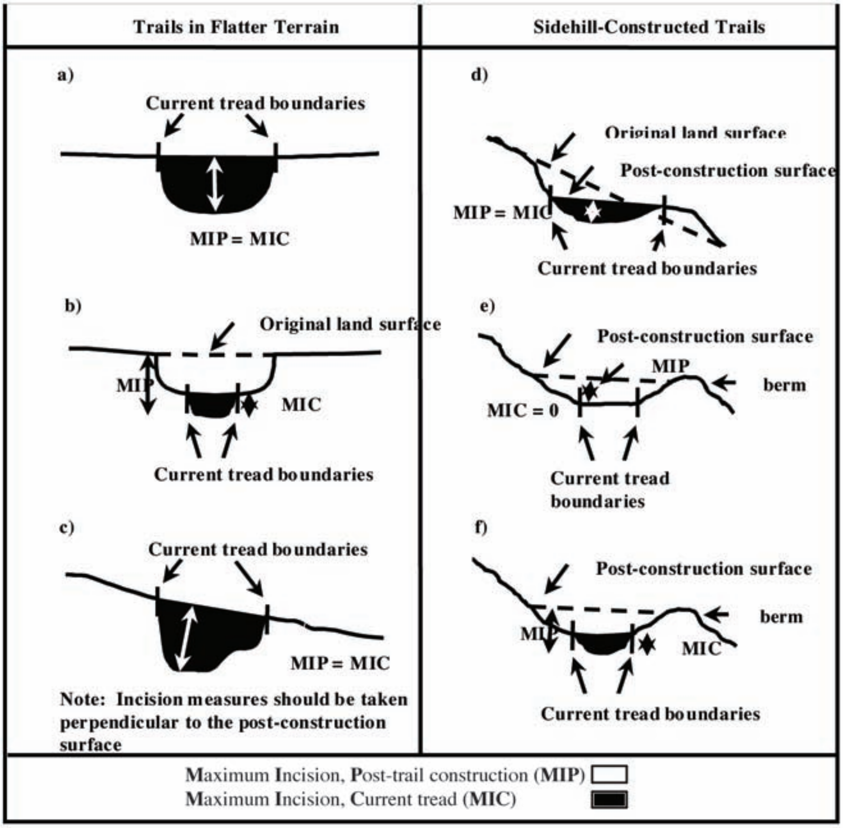


Figure 3. Diagrams illustrating the application of maximum incision measurements for trails in flat vs. sloping terrain. Source: Farrell and Marion 2002.

These adaptations were applied in a study of hiking trails in Torres del Paine National Park, Chile, with results indicating substantial differences in the two soil loss measures. MIC averaged 0.4 in. for low-use trails to 1.2 in. for high-use trails, while MIP averaged 3.1 in. on low-use trails and 5.9 in. on high-use trails (Farrell and Marion 2002). Furthermore, MIC measures remained substantially smaller regardless of trail position. Average MIC values were 0.8 in on trails in flatter valley-bottom positions and 1.2 in. in steeper mid-slope positions, while MIP values averaged 3.9 in. and 5.5 in. respectively. These findings emphasize the importance of providing more explicit guidance, including written procedures and diagrams, to guide maximum incision measurements.

Current research by the lead author is focusing on the further development of cross-sectional area (CSA) procedures, building on the work described above. CSA assessment methods are applied to transects oriented perpendicularly to trail treads at sample points as previously described for the maximum incision measures. Many vertical measurements are taken along the transect line across the width of the trail to provide an accurate estimate of the area of soil loss in a plane extending from the transect line to the tread surface.

The vertical measurements can be taken at a fixed interval or at variable intervals based on changes in the microtopography of the tread surface (see Figure 4 in Manning et al., this volume). Recent research conducted at Zion National Park (not reported here) compared the fixed and variable methods and will provide guidance on the selection of a fixed interval distance. An added advantage of CSA procedures is the ability to extrapolate findings to provide estimates of aggregate soil loss for an entire trail.

Monitoring visitor-created informal trails

So far the discussion of trail assessment and monitoring methods has focused on formal or established trails. However, visitor-created informal trails present a different set of challenges to management and monitoring (Leung et al. 2002). Since informal trails are not planned and constructed, they are usually poorly located with respect to terrain, and they receive little or no maintenance. These factors substantially increase their potential for degradation in comparison with formal trails. The proliferation of informal trails may increase habitat fragmentation and can directly threaten sensitive habitats when crossed or accessed by unplanned trails. From a social perspective a web of informal trails create a visually scarred landscape and may lead to safety and liability concerns. Due to their ecological and social significance, informal trails are a common indicator selected in different implementations of NPS's VERP planning framework (Bacon et al., this volume; Manning et al. 2005) as well as in the agency's Vital Signs monitoring program (Monz and Leung, this volume).

Monitoring can provide timely information on the extent, distribution, and condition of informal trail segments. Such information can serve as a warning sign of resource degradation and habitat intrusion and can trigger management actions if standards established to specify minimum acceptable conditions are exceeded. Some major monitoring questions related to informal trails include:

- What are the alternative indicator measures and monitoring techniques?
- Are there efficient methods to monitor informal trails without field mapping them all?
- How do the methods compare with respect to accuracy, precision/consistency, and efficiency?

As mentioned earlier, there are three general approaches to informal trail monitoring, with increasing levels of complexity and field time requirements. Major developments are currently occurring with the rapid advancement of geospatial technologies, such as geographic information systems (GIS), global positioning systems (GPS), and digital spatial data. These technologies are particularly relevant to informal trail monitoring because of their dispersed spatial distribution. The following discussion focuses primarily on examples of recent applications of geospatial technologies for monitoring informal trail networks.

GPS mapping. In a recent study of visitor carrying capacity in Boston Harbor Islands National Recreation Area, informal trails were selected as a resource-based indicator (Leung and Meyer 2004; Manning et al. 2005). The park consists of 34 units (islands and peninsulas) that received 262,000 visits in 2002. Georges, Grape, and Peddocks Islands and World's End Peninsula are popular destinations within the park. A professional-grade handheld Trimble GPS unit was used to map informal trails on all park units that have discernable signs of visitor use. Each informal trail segment was mapped and its condition rated using a four-point condition-class system (Leung et al 2002). Based on the GPS data, three alternative indicator measures were derived, including total length of informal trails, density of informal trails (length/unit area), and spatial proximity of informal trails to sensitive resources. Results show that World's End had about 76,000 ft of informal trails (total length measure) or 277 ft/acre (density measure), both of which are the highest among all units (Figure 4). Other islands with a significant presence of informal trails include Georges (9,329 ft) and Peddocks (7,049 ft), though the larger size of Peddocks Island resulted in a lower density value (33.5 ft/acre). In contrast, some small islands, such as Raccoon (3.6 acres) and Langlee (5.2 acres) Islands, had low total lengths of informal trails but their density values were quite high (204 and 169 ft/acre, respectively). These results have aided the park in selecting the preferred indicator measure (density of informal trails) and establishing associated standards.

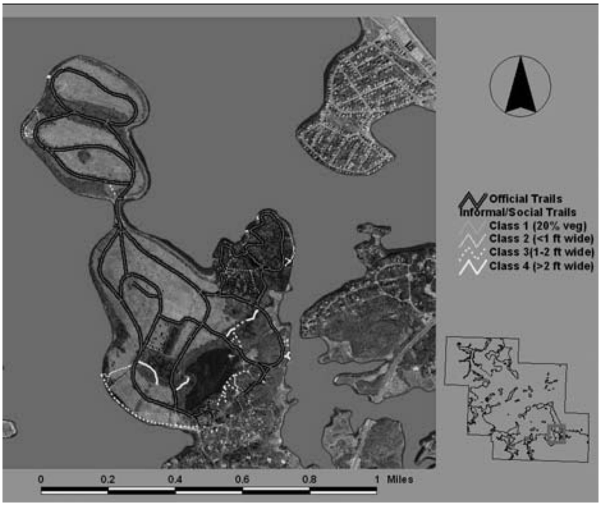
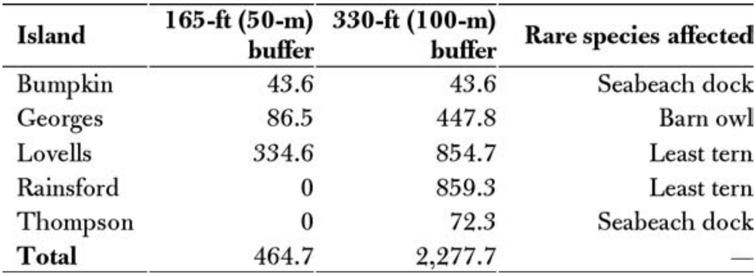


Figure 4. Formal and informal trail networks in World's End Peninsula, Boston Harbor Islands National Recreation Area.

When the informal trails data layer was integrated with other layers, such as locations of rare plant and animal species, proximity-based indicator measures can be derived that are indicative of visitor trampling disturbance within sensitive resource areas. Two proximity levels, 165 ft (50 m) and 330 ft (100 m) from rare species locations, were applied in the Boston Harbor Islands study (Table 2). Results show that the barn owl, least tern, and seabeach dock rare species may be threatened by visitor use on Bumpkin, Georges, and Lovells Islands.

Digital orthophotography. The increasing availability of high-quality remotely sensed spatial data can aid in increasing the coverage and efficiency of monitoring informal trail networks. One type of spatial data that is particularly promising is digital orthophoto quadrangles (DOQs), which are computer-generated images of aerial photographs that combine the image characteristics of a high-resolution photograph with the geometric qualities of a map. DOQs are georectified and georeferenced and can therefore be integrated with other GIS data layers.

The procedures involved in extracting informal trail data from the DOQs were pilot-tested in the Yorktown area of Colonial National Historic Park. Heads-up or on-screen digitizing of informal trails was performed on infrared DOQs (0.5-m reso-



Island	165-ft (50-m) buffer	330-ft (100-m) buffer	Rare species affected
Bumpkin	43.6	43.6	Seabeach dock
Georges	86.5	447.8	Barn owl
Lovells	334.6	854.7	Least tern
Rainsford	0	859.3	Least tern
Thompson	0	72.3	Seabeach dock
Total	464.7	2,277.7	—

Table 2. Lengths of informal trails (ft) that fall within 165 ft or 330 ft of known locations of rare plant and animal species.

lution) in ArcGIS 8.3 software. Preliminary test results show that informal trails could be digitized efficiently from DOQs with a modest level of training, but the quality of digitized informal trail data was dependent on (1) the scale (zooming factor) at which digitizing was conducted, (2) tree canopy, and (3) general visibility that required human judgment.

Comparing GPS and DOQ methods. Because both GPS and DOQs are being applied to informal trail monitoring, an important question is how the two methods compare with respect to accuracy and efficiency. In order to address this question, an identical set of informal trails from a local park in Cary, North Carolina, were assessed using both methods. Seven informal trails (total length 1.12 mi) were digitized from color DOQs (6-in resolution; 1999) and mapped using a professional Trimble GPS unit with sub-meter accuracy, the latter serving as the "true" reference data. The positional accuracy, total length of informal trails, and efficiency were evaluated. Based on 35 randomly selected test points along the informal trail routes, the average positional error of digitized trails was 5 ft, with a range of 0.013 to 17.6 ft (S.D. = 4.1 ft). All digitized trails were shorter than their GPS-mapped counterparts, with differences ranging from 1 to 45 ft. The difference in cumulative length was 113 ft, or 1.9%, for all 7 trails, which is considered to be low. Despite the positional and length errors, DOQ digitizing offered a much more efficient solution to assessment and monitoring for areas where trails are not obscured by tree cover. In this test the time required to implement the DOQ method was only 26 minutes, compared to 2.5 hours for GPS field mapping. This gap in efficiency is expected to be even wider in national parks since more travel time is needed to cover larger, more rugged, and less accessible landscapes.

The second author, along with the first author and colleagues from Aldo Leopold Wilderness Research Institute and St. Lawrence and Colorado State Universities, are currently conducting additional research to examine alternative methodologies for monitoring informal trails in different protected natural areas.

Concluding remarks

This paper reviewed some recent developments in methodologies for monitoring trail conditions on formal and informal trail networks. Objective methods have been developed and are available to protected area managers for monitoring the location, extent, and condition of trails. These tools are being refined and implemented more efficiently with the help of advancing geospatial technologies. However, there are trade-offs between the efficiency and accuracy and richness of alternative data collection methods. For example, geospatial methods are of little benefit for assessing tread conditions (e.g., erosion or muddiness) along trails but appear to be superior in monitoring changes in the lineal extent of informal trail networks in situations where they are visible from airplanes or satellites. The choice of monitoring methods and indicators is based on information needs and staffing and equipment availability. The development and use of standardized methods is also encouraged so that monitoring results can be compared and evaluated in a regional context.

Several trends are evident from our discussion. There are increasing applications of trail monitoring internationally in response to growing ecotourism visitation in global protected areas. Many of these areas do not possess the same level of financial and human resources, so streamlined or efficient procedures may be a necessary choice. Condition-class rating systems can be an attractive low-cost solution. Secondly, soil erosion is a key indicator in trail condition monitoring, and research efforts will continue to focus on this indicator to increase its accuracy, precision, and efficiency. Thirdly, geospatial technologies are becoming an essential tool in trail monitoring, though its potential is still being explored. The utility of low-cost GPS units needs to be further explored since they are more accessible to protected area managers and park volunteers.

Other methodological considerations that may be important for further examination include the increasing engagement of park volunteers, conservation organizations, and student groups in monitoring and its implications on the quality of data. Monitoring methods may need to be developed with an acceptable level of robustness so inter-rater variability is reduced when multiple volunteers with different backgrounds are involved. Further research will likely result in more effective trail impact indicator measures that benefit both VERP and Vital Sign monitoring programs in NPS.

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