Contributed Articles

STATE OF SCIENCE

The science of trail surveys: Recreation ecology provides new tools for managing wilderness trails

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Figure 1. Authors Logan Park (left) and Jeremy Wimpey assess a trail in Acadia National Park, Maine.

THIS ARTICLE REVIEWS RECENT RECREATION ECOLOGY research focused on developing new survey methods for assessing formal and informal trails or unsurfaced roads in wilderness and backcountry settings (fig. 1). Recreation ecology examines resource impacts caused by or related to visitor use. A brief review of research related to trail sustainability is included to illustrate factors that influence common types of trail degradation. These studies are producing new information and tools for park managers engaged in trail, carrying capacity, and other park planning and management decisions. Results can document the nature and severity of trail impacts and design deficiencies for planning and management decision making. For example, such data can justify staffing and funding requests to improve trail sustainability by relocating or reconstructing the worst trail segments, which will lower recurring maintenance costs.

Many park trails, especially those created before the advent of modern trail construction guidelines, were not sustainably designed. It is not surprising, therefore, that some park wilderness and backcountry trail systems quickly degrade under heavy traffic (fig. 2). A survey of National Park Service (NPS) backcountry and wilderness managers found that trail impacts were regarded as the most severely pervasive visitor impact problem, with 50% of all parks reporting trail impacts occurring in most or many areas (Marion et al. 1993). The most common trail impacts reported by park staff included soil erosion (44% of parks), trail widening (31%), braided/multiple trails (29%), informal trails (29%), and excessive muddiness (25%). These trail-related impacts are of great concern in wilderness areas (Abbe and Manning 2007), which are managed to maintain resource conditions that are "untrammeled by man . . . protected and managed so as to preserve [their] natural conditions" (16 USC 1131–1136). Moreover, trails that are designed or reworked to meet sustainability guidelines can reduce future maintenance costs and conflicts with the "minimum tool" wilderness management requirements.

Abstract

Recreation ecology examines the effects of recreation on protected area ecosystems. One core focus of recreation ecology research is trail science, including the development of efficient protocols to assess and monitor the type and severity of resource impacts, analyses to improve knowledge of factors that influence trail conditions, and studies to assist land managers in improving trail design, maintenance, and visitor management. This article reviews alternative trail survey methodologies most useful for the management of wilderness and backcountry trail networks. Illustrations and implications from survey data for trail planning, design, and management are included.

Key words

sustainable trail design, trail impacts, trail survey methods

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Figure 2. Hikers on a wide, eroded trail along the Blue Ridge Parkway, Virginia.

Recreation ecology and trail science

Regression modeling and other relational analyses used to investigate trail degradation reveal the influence of various factors on the sustainability of a trail to traffic (Leung and Marion 1996; Nepal 2003). Soil loss, generally considered to be the most significant and irreversible form of trail impact, is highest when trails have steep grades and are parallel to the landform grade or aspect, called fall-line alignments (Olive and Marion 2009). Steep trail grades accelerate soil erosion, and incised fall-aligned trails trap and channel water directly down their treads. The amount of rock in trail substrates and the density and effectiveness of tread drainage features (e.g., water bars, grade reversals, outsloped treads) are also important factors affecting soil loss. Regression modeling reveals that sustainable designs can also effectively reduce trail widening, which impacts adjacent vegetation and soil. Steep fall-aligned trails permit and even encourage the lateral movement of hikers, which widens trails, particularly when soil erosion produces incised treads with significant rockiness and root exposure (Wimpey and Marion 2010). Trail widening and the formation of multiple braided treads are also common in flat, poorly drained terrain, particularly when hikers seek to avoid wet and muddy conditions. In contrast, side-hill constructed trails, particularly when crossing steeper landform grades, effectively constrain trail widths.

Three types of trail surveys

Traditionally implemented with measuring wheels and data recorded on paper forms, trail surveys increasingly use global positioning system (GPS) devices to locate and map inventory data with a high degree of accuracy. GPS collection allows for electronic data entry, which enables direct downloads of trail data to computers, saving much time and avoiding recording and transcription errors. Three general types of trail surveys have been developed to assist in managing trail systems:

- Trail attribute inventory
- Trail condition assessment
- Trail prescriptive management assessment

A **trail attribute inventory** uses professional-grade GPS units to map *trail system characteristics*, providing accurate geographic information systems (GIS) trail layers for mapping, planning, analytical, and decision-making functions. Common trail attribute data are use type, cultural/historical features, attraction features, hiking difficulty and accessibility, maintenance features (e.g., signs, gates/barriers, bridges, culverts/water bars), and sustainability attributes (e.g., trail grade, slope alignment angle, slope ratio, trail substrates). Inventories of informal trail networks provide data on their spatial distribution and aggregate lineal and areal extent.

Trail attribute inventories can provide highly accurate GIS formal and informal trail layers. During the field survey, attributes such as use type and tread substrates can be associated with each line segment. Point features, such as gates, bridges, campsites, and vistas, can be collected and assigned attributes, and even digital photos can be linked and geo-referenced to these points. At Chesapeake and Ohio Canal National Historical Park, survey-grade GPS units were used to inventory and map 14.7 miles (23.7 km) of formal trail and a surprising 19.3 miles (31.1 km) of informal trails, posing a direct threat to the park's many rare plant species. Trail inventory data are useful for general management, trail, wilderness, and carrying capacity planning; mapping and GIS analyses; and

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Figure 3. A Trimble GPS was used to map all formal trails (blue) and informal trails (red) in the Potomac Gorge area of C&O Canal National Historical Park.

Table 1. Point sampling condition assessment data for two park trails in Zion National Park, Utah

Indicator	West Rim Trail		LaVerkin Trail	
Trail width (mean, in [cm])	41.9	[106.4]	45.7	[116.1]
Max incision (mean, in [cm])	1.9	[4.8]	3.2	[8.1]
Area of disturbance (ft^2 [m^2])	178,192	[16,572]	97,768	[9,092]
Soil loss				
Mean, in^2 [cm^2]	36.1	[233]	92.4	[596]
Sum, yd^3 [m^3]	473	[362]	609	[466]
Yd^3/mi [m^3/km]	49	[23]	125	[59]
Trail substrates[1]				
Exposed soil (%)	64.2		88.3	
Exposed rock (%)	20.2		5.8	
Vegetation cover (%)	3.3		1.5	
Muddiness (%)	3.5		0	

Source: Marion and Hockett 2008.
[1]Proportion of trail transect width.

park management decision making. Analysis of trail grade and slope ratio for sustainability can be conducted by combining trail inventory data with high-resolution terrain models (such as lidar-derived terrain models). In the wilderness setting, these high-tech analyses can represent the minimum tool by allowing managers to minimize field time while providing the ability to assess vast trail systems electronically in the GIS environment (fig. 3).

Trail condition assessments document trail resource conditions to provide data on the type, severity, and, in some surveys, location of specific types of *trail impacts*. A commonly applied *point sampling survey* method assesses trail conditions at transects established at a fixed interval (e.g., every 300 or 500 ft [92 or 153 m]), following a randomly selected first point (Cole 1991; Marion and Leung 2001). This approach provides excellent data for characterizing and monitoring continuous trail attributes (trail width) or common impacts (trail incision/soil loss) (table 1). Data can be compared against quantitative Limits of Acceptable Change/Visitor Experience and Resource Protection framework standards of quality or simply evaluated to determine where and how much trail conditions are changing over time.

A *problem assessment survey* provides census data by recording every occurrence of predefined impact problems, such as excessive trail width, soil loss, or muddiness (Leung and Marion 1999) (table 2). Other attributes, such as the efficacy of tread drainage features, can also be included. This method provides useful location data for directing trail maintainers seeking to remedy impacts, and better characterizes less common forms of trail impact such as mudholes and braided trails.

Condition class surveys apply impact ratings based on written descriptions of increasing levels of trail impact to characterize sections of trails with similar conditions (Wimpey and Marion 2011). Higher ratings connote greater trail impact. This highly efficient survey method is most commonly applied to informal trail networks to map and track the number of trail miles by impact class. At Denali National Park (Alaska) this procedure was implemented as part of a suite of trail inventory and assessment procedures, allowing for rapid and cost-effective monitoring of informal trails across several million acres (fig. 4, page 64).

Trail prescriptive management assessments can evaluate and document *maintenance needs, sustainability attributes, use-type capabilities, and relocation options*. *Prescriptive maintenance work logs* can document the condition of or work needed on existing trail features, or the need for new features, including gates/barriers, bridges, signs, and tread drainage features (culverts, water bars, ditching) (Williams and Marion 1992). Work log assessments must be applied by experienced trail professionals, who prescribe the specific types of trail work needed and provide materials and labor estimates (table 3).

Sustainability analyses are currently being developed to collect and analyze data on trail grade, trail alignment angle to the prevailing landform grade, and tread substrates. Such analyses can be conducted with data from walking surveys, but when available, high-resolution topographic data derived from airborne lidar sen-

Table 2. Problem assessment condition data for the Spence Field to Doe Knob portion (7.7 mi) of the Appalachian Trail in Great Smoky Mountains National Park, Tennessee and North Carolina

	Occurrences		Total Lineal Distance		
Indicator	no.	no./mi (km)	ft (m)	ft/mi (m/km)	%
Soil loss: 1–1.9 ft (0.3–0.6 m)	30	3.9 (2.4)	6,065 (1,850)	788 (149)	15.0
Soil loss: 2–2.9 ft (0.3–0.9 m)	2	0.3 (0.2)	96 (29)	12 (2)	0.2
Excessive grade: >20%	6	0.8 (0.5)	2,357 (719)	306 (58)	5.8
Multiple treads	21	2.7 (1.7)	1,218 (371)	158 (30)	3.0
Excessive width: 3–6 ft (0.9–1.8 m)	15	1.9 (1.2)	1,455 (444)	189 (36)	3.6
Excessive width: >6 ft (1.8 m)	4	0.5 (0.3)	289 (88)	38 (7)	0.7
Wet soil	11	1.4 (0.9)	1,411 (430)	183 (35)	3.5
Drainage features					
Ineffective	110	14.2 (8.8)			
Intermediate	46	6.0 (3.7)			
Effective	65	8.4 (5.2)			

Source: Marion 1994.

sors offer a more promising option for conducting detailed evaluations. Lidar-based techniques are a subject of current research to develop GIS analyses for efficiently evaluating the sustainability of entire trail systems. Such data can also facilitate the development and application of criteria for evaluating the amount and type of use trails can accommodate, and relocation alternatives for trail segments that receive low sustainability scores.

Initial work has applied lidar data to assess trail grades (Keen 2011) and trail sustainability based on trail grades and topographic alignments (Wimpey 2011). Figure 5 (next page) illustrates exploratory analyses using high-resolution terrain models for assessing trail sustainability. U.S. Forest Service and National Park Service units in Georgia and West Virginia have employed lidar analyses of existing trail and road systems as part of assessment and planning efforts. On the Chattahoochee-Oconee National Forest, a lidar terrain model provided data to assess trail grades at an off-road vehicle trail system. Trail planners working with the National Park Service to develop a trail system in New River Gorge National River (West Virginia) evaluated preexisting extraction routes (old logging, mining, and agricultural roads) for sustainability and inclusion in a new trail system. Routes were collected via GPS and digitization from historical aerial imagery and evaluated for grade and slope ratio using lidar terrain models collected by the state and the U.S. Army Corps of Engineers.

Depending on the needs at a given park, any combination of trail attribute inventory, condition assessment, and prescriptive management survey can be used. For example, a trained GPS field technician (or two-person team) can conduct an initial baseline trail attribute inventory for park maintenance records and planning efforts. Since the expense and time are related primarily to getting staff on location as opposed to data collection, adding a condition assessment increases total cost very little. In combination, these methods provide more comprehensive and detailed documentation of trail resource conditions and management needs. Such data can guide management teams in planning and decision making by providing relevant quantitative data on many aspects of trail infrastructure, in addition to detailed GIS maps of trail system, trail conditions, problem locations, and sustainability evaluations.

Table 3. Prescriptive worklog summary for the Thunder Mountain Trail (2.4 mi), Delaware Water Gap National Recreation Area, New Jersey

Item	Units	Linear Feet (m)	Estimated Labor (hrs)
Steps	41	n/a	68
Step-stones	8	n/a	6
Ditching	20	187 (57)	29
Water bar	14	103 (31)	22
Bridge	2	56 (17)	188
Bog bridge	44	350 (107)	80
Side-hilling	355	n/a	28
Total			421

Source: Williams et al. 1992.

Discussion

Application of improved trail survey methodologies for collecting spatially referenced data and new technologies, particularly accurate GPS units, lidar-derived high-resolution terrain models, and advanced GIS software, offers substantial promise for the

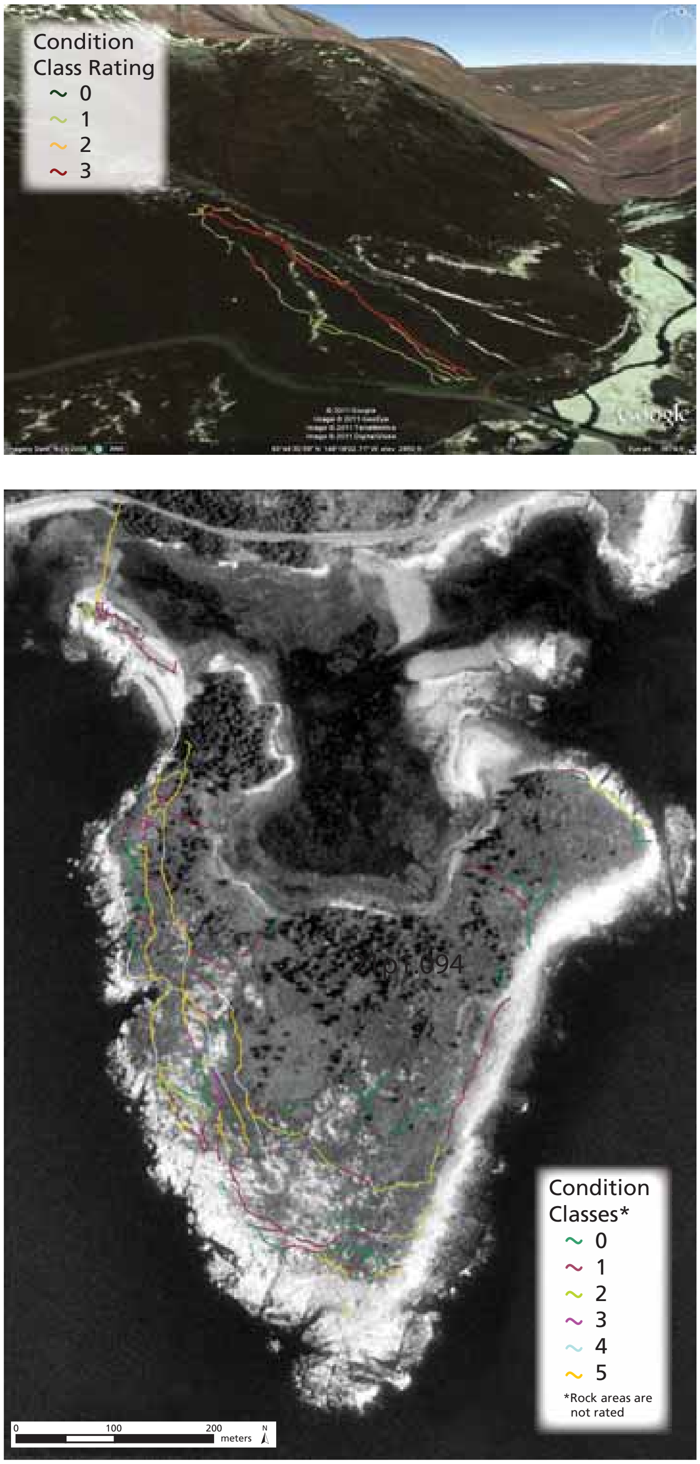

Figure 4. Condition class ratings applied to a mapped informal trail network in the Savage Box area, Denali National Park (above, top), and on Little Moose Island, Acadia National Park (above, bottom) (Marion and Wimpey 2011; Manning et al. 2006).

DENALI: JEREMY WIMPEY; ACADIA: ACADIA NATIONAL PARK GIS PROGRAM

JEREMY WIMPEY

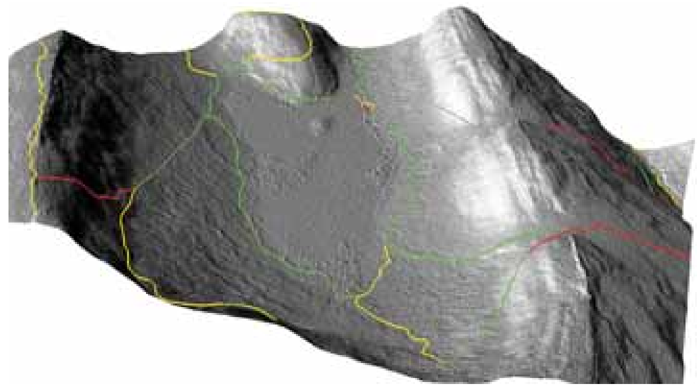

Figure 5. Sustainability ratings derived from lidar data and GIS analytical evaluations of trail slope ratios: red = nonsustainable, yellow = borderline, green = sustainable (Wimpey 2011).

continuation of this work. While limited funding is a significant barrier, there are exciting scientific and managerially useful topics deserving of greater research attention. Current research is exploring the capabilities of new geospatial data sets and analyses and their ability to locate, characterize, and assess trail systems. Recent work has shown that formal and some informal trails can be mapped and analyzed directly from lidar data (Kincey and Challis 2010). The development of such tools will improve the ability of managers to remotely evaluate existing and proposed trails and trail systems, reducing staff time in the field.

Though vegetation, wildlife, and recreation management programs in parks are generally "science-based," trail management and its associated literature have traditionally not been based on scientific research. Though few in number, recreation ecology scientists are increasingly focused on expanding trail science knowledge, including development of trail survey methods, trail condition assessment protocols, and the relational analyses needed to identify and understand factors influencing trail degradation. This work continues to translate scientific information into usable knowledge for park managers, particularly as it relates to assessing and improving the sustainability of trail systems.

Park managers can integrate components from any of the three trail survey options described, and many of the tools and kinds of expertise needed are present in parks (e.g., survey-grade GPS units, clinometers, GIS software). Where needed, resource management and GIS staff can train seasonal field staff to collect data, even as a collateral duty. Lidar data can be contracted or obtained from a variety of sources. The authors have helped many national parks and other protected areas to develop and implement monitoring based on these techniques, with training materials and support provided to sustain the monitoring effort.

Sustainable [trail] designs can also effectively reduce trail widening, which impacts adjacent vegetation and soil.

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