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Assessing trail conditions in protected areas: application of a problem-assessment method in Great Smoky Mountains National Park, USA

YU-FAI LEUNG[1] AND JEFFREY L. MARION[2]*

[1]*Department of Parks, Recreation and Tourism Management, North Carolina State University,4008 Biltmore Hall, Raleigh, North Carolina 29675-8004, USA and* [2]*USGS Patuxent Wildlife Research Center, Virginia Tech Cooperative Park Studies Unit (0324), 304 Cheatham Hall, Blacksburg, Virginia 24061, USA*

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Summary

The degradation of trail resources associated with expanding recreation and tourism visitation is a growing management problem in protected areas worldwide. In order to make judicious trail and visitor management decisions, protected area managers need objective and timely information on trail resource conditions. This paper introduces a trail survey method that efficiently characterizes the location and lineal extent of common trail problems. The method was applied to a large sample of trails within Great Smoky Mountains National Park, a high-use protected area in the USA. The Trail Problem-Assessment Method (TPAM) employs a continuous search for multiple indicators of pre-defined tread problems, yielding census data documenting the location, occurrence and extent of each problem. The present application employed 23 different indicators in three categories to gather inventory, resource condition, and design and maintenance data of each surveyed trail. Seventy-two backcountry hiking trails (528 km), or 35% of the Park's total trail length, were surveyed. Soil erosion and wet soil were found to be the two most common impacts on a lineal extent basis. Trails with serious tread problems were well distributed throughout the Park, although trails with wet muddy treads tended to be concentrated in areas where horse use was high. The effectiveness of maintenance features installed to divert water from trail treads was also evaluated. Water bars were found to be more effective than drainage dips. The TPAM was able to provide Park managers with objective and quantitative information for use in trail planning, management and maintenance decisions, and is applicable to other protected areas elsewhere with different environmental and impact characteristics.

Keywords: trail degradation, impact assessment, trail surveys, trail problem-assessment method, Great Smoky Mountains National Park

* Correspondence: Dr Jeffrey L. Marion Tel: +1 540 231 6603 Fax: +1 540 231 3698 e-mail: cpsu@vt.edu

Introduction

In national parks and other protected areas (parks hereafter) worldwide, trails of various types (e.g. footpaths, hiking trails, bridleways, bicycle paths) commonly exist in support of three major functions, namely providing access, offering recreational opportunities, and protecting park resources by concentrating visitor use impacts on tread surfaces. Trails are generally regarded as a necessity in parks, a recreation and tourism resource that requires both maintenance and protection. The extent to which the conditions and functionality of this linear resource are maintained thus provides an objective measure of the sustainability of recreation and tourism (Griswold 1995).

Over the past few decades, degrading trail conditions have been increasingly reported in different park systems and have become a common concern amongst park managers (Marion *et al.* 1993; Ruff & Maddison 1994; Tasmania Parks and Wildlife Service 1994). This problem is particularly evident at popular parks where visitation is high and hiking is a common activity. Major forms of trail degradation include wet muddy treads, tread widening, tread incision, and soil erosion (Hammitt & Cole 1998). These impacts often result in difficult and unsafe travel conditions, and have been found to affect the quality of recreational experiences (Vaske *et al.* 1982). Excessive soil erosion on trails may also contribute substantially to the overall watershed sediment yield (Harden 1992).

In order to make judicious trail and visitor management decisions and to set priorities for actions, park managers require objective and timely information about trail resource conditions. Although the trail degradation problem has received research attention for decades (Leung & Marion 1996), most previous studies were one-time investigations that employed elaborate field measurements and laboratory analyses, which are too time-consuming or cost-prohibitive for use by park managers. Systematic efforts devoted to the development of efficient visitor impact assessment and monitoring (IA&M) survey methodologies have been focused largely on campsites and other recreation nodes rather than linear corridors such as trails (Marion 1995). The primary purpose of this study was to devise a trail IA&M method that emphasized management utility, and apply this method to a large sample of hiking trails in Great Smoky Mountains National Park (GSMNP), a high-use national park in south-eastern USA.

This research was prompted by growing management and visitor concerns over degrading trail resource conditions within GSMNP. Such concerns were due in part to declining Park budgets, which have restricted trail maintenance activities, and to increases in trail use. Disproportionate resource impacts from horse use have also been cited as a potential cause. Responding to such concerns, the US National Park Service funded a comprehensive study to evaluate current trail conditions and management practices of the Park (Marion 1994).

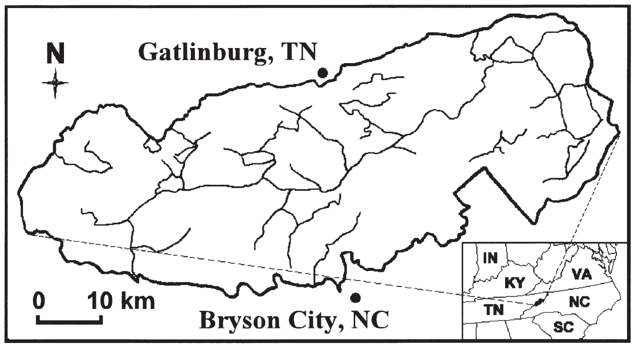

Figure 1 Location of Great Smoky Mountains National Park, USA, and the distribution of surveyed trail segments (n = 72; 528 km).

Methods

Study area

The GSMNP is located in south-eastern USA, within the southern Appalachian mountains along the Tennessee and North Carolina state border (Fig. 1). Established in 1934, the Park has grown to 2084 km^2 in size and contains 114 km of the Appalachian National Scenic Trail, which stretches 3480 km across 14 eastern states. The ecological and cultural importance of the Park has been recognized internationally, as it is both an International Biosphere Reserve and a World Heritage Site. Eighty-three per cent of the Park area is also under consideration for wilderness designation (National Park Service 1981).

The enabling legislation of GSMNP directs Park managers to provide for visitor use so long as the Park's resources and natural processes are 'essentially unaltered' (National Park Service 1981). This presents a significant management challenge in this Park, because GSMNP reported 9.9 million recreation visits in 1997, the third highest use of any unit in the National Park system (National Park Service 1997*b*). Although many visitors remain close to their cars, day hiking, backpacking, and horse riding are popular visitor activities. Data provided by a 1985 study placed the number of day hikers at approximately 700 000 annually (Peine & Renfro 1988), while 106 000 backcountry overnight stays were reported by the Park in 1997 (National Park Service 1997*b*). GSMNP receives more horse use than any park east of the Rocky mountains (National Park Service 1995).

GSMNP has 1496 km of official park trails. Much of the trail system was developed by the Civilian Conservation Corps (CCC) Program between 1933 and 1943. These old woods roads and trails are generally well-graded and some have extensive stone work. Some trails follow historic settler wagon roads or railroad grades, the latter associated with logging activities which began about 1880. The wagon roads vary in design, often crisscrossing streams, ascending ridges, and have shown evidence of severe erosion long before their use as trails (Bratton *et al.* 1977*a*). The narrow railroad corridors are similar to the CCC trails, with reasonable grades, stone work and bridges. Other roads and trails were built by the National Park Service, often to former fire towers and popular backcountry destinations.

Two-thirds of the Park trail system (1025 km) are open to horse use. Horseback riding has long been a popular activity in the Park. A large portion of the horse use is generated by five horse stables operating within the Park under concession permits. However, the stables predominantly use trails located in the more accessible and developed front-country areas of the Park. Stock concession operators are required to routinely maintain the front-country trails they use, typically through application of both coarse and fine gravel. Management concern over resource impacts from horse use resulted in a restriction on the number of horseback riding concession permits, with facilities and horse allotments frozen at 1975–76 levels (National Park Service 1981). Private stock account for much of the use on backcountry trails. Although horseback riding is predominantly a day-use activity, there are no figures on day use by privately outfitted horse parties. Permit data on Park overnight stays indicate that groups camping with their horses include more than 10 000 animals annually. Approximately 85% of this use is supported by road-accessed campsites, but 51 of 84 backcountry campsites and 13 of 18 shelter sites are open to visitors with horses.

Previous investigations on trail degradation in GSMNP include a parkwide survey by Bratton *et al.* (1977*a*, *b*) and an Appalachian Trail study by Burde and Renfro (1986). No trail assessment or monitoring surveys, however, are conducted on a routine and systematic basis. Rather, trail conditions are informally observed and reported on by Park staff during routine patrols. A new backcountry recreation management plan calls for the development and use of standardized Annual Trail Evaluations and Prescriptive Maintenance Work Logs (National Park Service 1995). Trail maintenance work is conducted by Park trail maintenance crews and a number of volunteer organizations and individuals. However, funding and staffing for this work are limited, and budget cuts in recent years have greatly reduced the extent and effectiveness of these efforts.

Trail assessment survey methods

A primary objective guiding survey development was the need to document the locations and extent of occurrence of

Table 1 Survey indicators included in the trail problem-assessment method as applied to Great Smoky Mountains National Park, USA. Types: L = Indicator is assessed as a lineal feature, beginning and ending distances are recorded, P = assessed as a point feature.

Indicator		*Indicator description*	*Type*
Inventory indicators			
Start point		Documentation of where measuring wheel was started.	P
End point		Documentation of where measuring wheel was stopped.	P
Use type:	Pedestrian	Segment is restricted to pedestrian use.	L
	Horse/Pedestrian	Segment is open to horse use.	L
Tread width:	Trail 61–183 cm	Segment is of trail width (61–183 cm).	L
	Trail on road 61–183 cm	Segment is on a road which has narrowed to 61–183 cm in width.	L
	Road >183 cm	Segment is on a road > 183 cm in width.	L
Resource condition indicators[1]			
Soil erosion:	30–60 cm 61–90 cm 91–120 cm, etc.	Segment has eroded below the estimated original, post-construction, tread surface by the amount specified.	L
Excessive root exposure		Segment has severe tree root exposure: tops/sides of roots are exposed.	L
Excessive width:	91–183 cm	Segment has expanded 91–183 cm wider than adjacent, more typical, sections of the trail.	L
	>183 cm	Segment is >183 cm wider than adjacent sections of the trail.	L
Wet soil		Segment has wet muddy soil over more than half of the tread width, including muddy soils or mudholes with standing water[2].	L
Running water on trail		Segment has running water on the tread.	L
Multiple tread		Segment has more than one definable tread.	L
Design and maintenance indicators			
Excessive grade		Segment has a grade exceeding 20%.	L
Gravelled tread		Segment has had gravel applied.	L
Trail corduroy		Segment has wood bridging installed for crossing wet soils.	L
Drainage dip:	Very effective	An obvious human-constructed dip and berm configured to divert water from the tread, evaluated in terms of its effectiveness.	P
	Partially effective		P
	Ineffective		P
Water bar:	Very effective	An obvious wooden or rock structure configured to divert water from the tread, evaluated in terms of its effectiveness.	P
	Partially effective		P
	Ineffective		P

(1) Staff assessed only trail segments exhibiting the described conditions for a lineal distance of 3 m or greater.
(2) Staff employed judgement in defining segments that would likely be wet during 'normal' soil moisture conditions, reducing their estimates if rain had recently fallen, expanding estimates during extended dry periods.

various tread problems, such as excessively muddy, wide or eroded treads. A variety of trail IA&M methods has been reviewed and compared by Coleman (1977), Cole (1983), and Leung and Marion (1999). The most common survey approach is systematic sampling in which measurements are taken at points located at a constant interval along a trail. While this sampling-based approach is able to characterize average trail conditions, it does not document the problem locations. In addition, frequency of occurrences and the lineal extent of specific impact problems can only be estimated from the sample with varying accuracy levels (Leung & Marion 1999). Finally, point measurement data cannot be used for evaluating trail condition standards that are of a maximum intensity type (e.g. unacceptable tread incision defined as ≥ 30 cm in depth), which requires complete records of unacceptable incidents, nor can they be used for directing maintenance crews to locations where tread work is needed.

The trail problem-assessment method (TPAM)

Recognizing the need for a trail IA&M methodology that yields more managerially relevant data, a survey method with a problem-oriented approach was developed. This trail problem-assessment method (TPAM) employed a continuous search for multiple indicators of pre-defined tread problems, yielding census data documenting the location and occurrence of each assessed impact problem. It permits efficient evaluation of a diverse array of trail survey indicators of interest to both managers and researchers. In the present survey, three categories of indicators were included, namely (1) inventory indicators to characterize trail type and use, (2) resource condition indicators to characterize the location, number, and lineal extent of pre-defined tread problems, and (3) design and maintenance indicators to document design problems (excessive trail grades) and maintenance features,

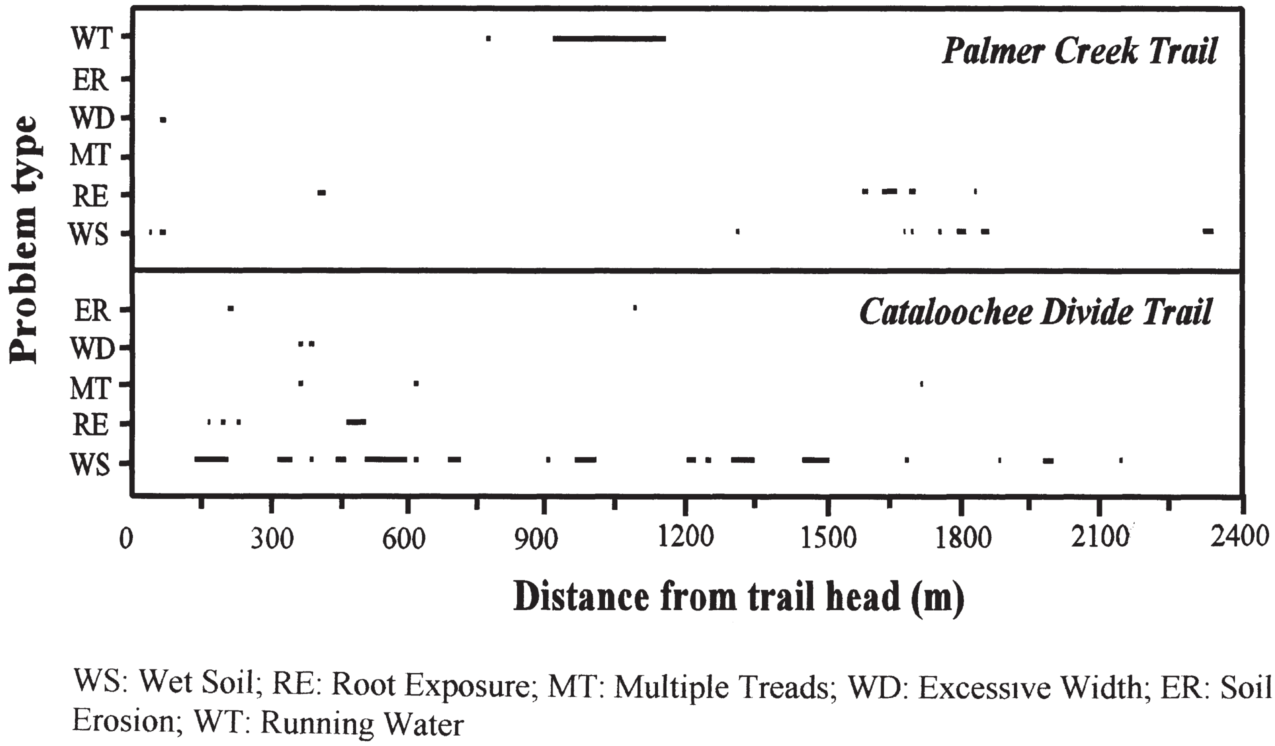

Figure 2 Strip chart showing the spatial extent, distribution and association of impact problems on two selected trails in Great Smoky Mountains National Park, USA.

such as the number and relative effectiveness of water bars and drainage dips constructed to divert water runoff from trail treads (Table 1).

Procedures

The field survey using the proposed method was applied by eight field staff working in pairs during the summer of 1993. Seventy-two trail segments (528 km) distributed throughout the Park were selected for the survey on the basis of use-related and environmental factors. Although the sample was not randomly drawn, its size was large enough to include a wide range of environmental and use-related conditions. The sample included most of the Park's heavily used and more highly degraded trails, and also many moderately and lightly used trails. The resulting sample included trails distributed evenly from all geographic regions of the Park and contained 25% of the Park's trail segments and 35% of the Park's total trail length (Fig. 1). The sample was also well distributed with respect to topographic position and elevation. For example, 9 trail segments (58 km) occurred in lower slope (drainage bottom) positions, 38 trail segments (232 km) in mid-slope positions, 18 trail segments (169 km) in upper slope (ridge-top) positions and 7 trails (69 km) in mixed slope positions. All of the Appalachian Trail within the Park was included in the sample. All, or portions of, 49 of the surveyed trails were open to horse use, totalling 343 km of the overall surveyed trail length.

Field staff assessed 23 indicators (Table 1) by pushing a trail measuring wheel (122 cm circumference) along each surveyed trail segment. All indicator names were coded to permit rapid recording on a simple form along with the cumulative distance from the trail head. For point features (e.g. water bars), staff recorded a single distance from the measuring wheel. For linear features (e.g. wet soil), they recorded the starting and ending distances of each occurrence. For resource condition indicators, only tread problems that exceeded a

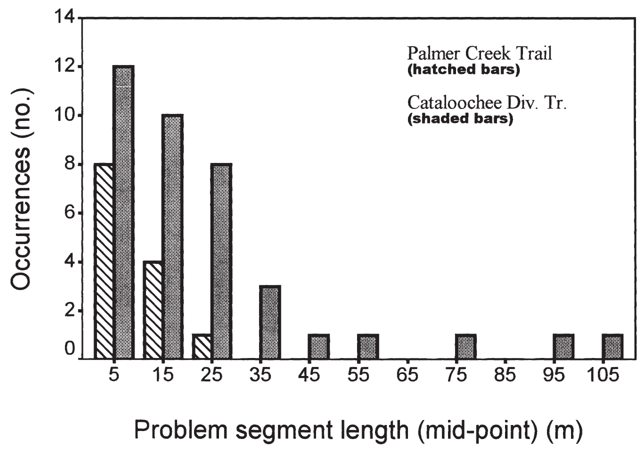

Figure 3 Histogram showing the frequency distributions of muddy (wet soil) segment lengths on two selected trails in Great Smoky Mountains National Park, USA.

Table 2 Summary of survey results from application of the trail problem-assessment method on two trails, namely Palmer Creek Trail (5.3 km in length) and Cataloochee Divide Trail (4.7 km in length) in Great Smoky Mountains National Park, USA.

Trail impact problem	*Palmer Creek Trail*					*Cataloochee Divide Trail*				
	Occurrences		*Total lineal distance*			*Occurrences*		*Total lineal distance*		
	(No.)	*(No./km)*	*(m)*	*(m/km)*	*(%)*	*(No.)*	*(No./km)*	*(m)*	*(m/km)*	*(%)*
Soil erosion (> 30 cm)	3	0.6	20	4	0.4	2	0.4	15	3	0.3
Multiple tread	1	0.2	20	4	0.4	6	1.3	52	11	1.1
Excessive root exposure	8	1.5	113	22	2.2	4	0.9	61	13	1.3
Excessive width (>183 cm)	2	0.4	21	4	0.4	3	0.6	34	7	0.7
Wet soil	13	2.5	122	23	2.3	38	8.1	921	194	19.5
Running water on trail	4	0.8	276	53	5.3	0	0	0	0	0

specified extent and length along the trail were assessed. For example, only soil erosion exceeding 30 cm in depth for a lineal distance of 3 m or greater was assessed (Table 1). Soil texture and elevation at which each soil erosion incident occurred were also recorded to permit relational analyses.

Wet soil included any saturated soil, such as mudholes and muddy soils from seeps or tread depressions that lasted more than a few days following rains. Running water from streams, springs, or seeps observed on the tread was recorded as running water on trail rather than wet soil, since the former is indicative of a greater potential for water erosion.

All obviously human-constructed tread drainage features, such as drainage dips and water bars (Hesselbarth & Vachowski 1996), were documented for each surveyed trail. For each drainage feature, the estimated effectiveness in diverting water off the tread was also rated as either very effective, partially effective, or ineffective.

The accuracy and precision in assessing the starting and ending points for each condition indicator were improved through the use of detailed descriptive procedures, colour photographs, staff training and supervision, routine swapping of field partners, and a mid-season quality assurance evaluation (Marion 1994). Preliminary results from the quality assurance evaluation indicated some variability in judgements of where tread problems started or ended, with greater consensus achieved when results were aggregated for entire trail segments. Survey data were input, stored and summarized in dBase III+, and the data set was exported to SPSS for Windows (ver. 7.0) for analyses and graph production.

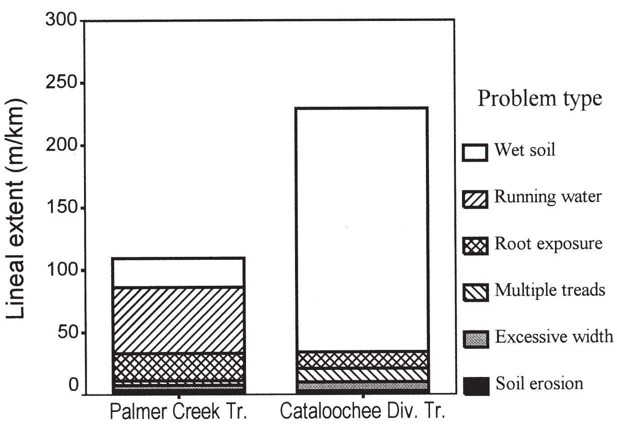

Figure 4 Stacked bar chart summarizing the lineal extent of impact problems on two selected trails in Great Smoky Mountains National Park, USA.

Results

Trail level

To illustrate the types of data and their presentation formats, two trails (Palmer Creek and Cataloochee Divide Trails) were selected as examples. The TPAM yielded useful survey data that could be presented in both original and summarized formats. A simple sequential listing of survey data (ordered by distance from the trail head) could provide managers with locational information on all tread problems and maintenance features. This information could be communicated to trail maintenance crews to direct needed tread work, such as the locations of wet muddy treads or ineffective tread drainage features. Graphical portrayal of trail impact problems in the form of strip charts (Fig. 2) facilitated rapid comparisons of the frequency and lineal extent of various problems. Such graphs could also permit visual evaluations of the spatial distribution and association of impact problems (e.g. wet soil and tread widening). Locations with two or more coexisting tread problems were readily identified in this presentation format, facilitating any response by trail crews for tread maintenance work or relocation.

Histograms were constructed to depict graphically frequency distributions of problem segment lengths. For example, wet soil segments on Palmer Creek Trail were relatively short (mean = 9 m, range = 3–24 m) and infrequent (13 occurrences), while those on Cataloochee Divide Trail were much longer (mean = 24 m, range = 3–107 m) and more numerous (38 occurrences) (Fig. 3). The TPAM permitted evaluations of maximum value standards (e.g. wet soil segments not to exceed 30 m in length) by documenting the lineal extent of all problem occurrences. For instance, if a standard for wet soil had been set at 50 m, the Cataloochee Divide Trail would have had four incidents of unacceptable segments (Fig. 3).

Table 3 Aggregate results of frequency of occurrences and lineal extent (km = distance [km] summed across all trails; % = per cent of each trail, averaged across all trails; m/km = number of m/km for each trail, averaged across all trails; Mean = distance (m), averaged across all trails) of survey indicators for all study trails (n = 72; 528 km) in Great Smoky Mountains National Park, USA.

	Occurrences		*Total lineal distance*			
Trail indicator	*(No.)*	*(No./km)*	*(km)*	*(%)*	*(m/km)*	*Mean (m)*
Inventory						
Use type: pedestrian	23	–	174.5	32.1		
Use type: horse/pedestrian	49	–	352.9	67.6		
Tread width: trail 61–183 cm	68	–	446.7	84.4		
Tread width: trail on road 61–183 cm	17	–	43.7	8.1		
Tread width: road > 183 cm	14	–	33.5	7.1		
Resource condition						
Soil erosion: 30–60 cm	634	1.2	19.5	3.5	35	270
Soil erosion: 61–90 cm	84	0.2	3.1	0.7	7	43
Soil erosion: ≥91 cm	16	0.03	1.0	0.4	4	13
Root exposure	365	0.7	3.9	1.0	10	55
Excessive width: 91–183 cm	150	0.3	3.1	0.6	6	43
Excessive width: >183 cm	26	0.1	0.5	0.1	1	7
Multiple tread	470	0.9	10.3	1.8	18	143
Wet soil	752	1.4	18.2	3.5	35	253
Running water on trail	227	0.4	4.2	1.0	10	58
Design and maintenance						
Excessive grade: >20%	131	0.3	7.9	1.4		
Gravelled tread	17	0.03	37.6	8.0		
Trail corduroy	19	0.04	0.2	< 0.0		
Drainage dip: very effective	837	1.6				
Drainage dip: partially effective	1522	2.9				
Drainage dip: ineffective	1778	3.4				
Water bar: very effective	1671	3.2				
Water bar: partially effective	891	1.7				
Water bar: ineffective	1242	2.4				

Tabular presentation of data provided the format for most comprehensively showing the frequency and lineal extent of tread problems (Table 2). The number of occurrences of tread problems provided a measure of how common different problems were. Conversion to number per km yielded a standardized measure that could permit comparisons across trails of various lengths. Cumulative or aggregate impact for each tread problem was represented by summing the lengths of each tread problem, reported as total lineal distance (m), standardized measure (m/km), and per cent of trail length (Table 2). The standardized measure was considered the best single measure for comparing the lineal extent of tread problems across different trails. Wet soil occurred extensively on Cataloochee Divide Trail, averaging 194 m/km, or 20% of the trail length (Fig. 4). Other impact problems were relatively infrequent on this trail. For Palmer Creek Trail, the overall lineal extent of impact problems was much lower (Fig. 4), although running water occurred on about 5% of the trail (Table 2), indicating a potential for future soil erosion problems.

Park-wide results

Inventory data

A summary of assessment data aggregated across all the sampled trails is presented in Table 3. Of the 72 trails surveyed, all or parts of 49 (68%) were open to horses and hikers, whereas 23 trails (32%) were restricted to hikers (Table 3). Of the 528 km of surveyed trail length, 353 km (68%) were open to horses and hikers and 175 km (32%) were restricted to hikers. The majority of surveyed trails (84%, 447 km) were constructed as trails of 61 to 183 cm in width. However, backcountry roads comprised 78 km of the sample, most of which were closed even to Park vehicles. A little over one-half of the roads (44 km) had narrowed to 61 to 183 cm in width.

Resource condition data

Soil erosion of trail treads was amongst the most common and perhaps the most significant resource impact assessed on the surveyed trails. Thirty-seven per cent of the total lineal extent of impact was related to trail erosion. Soil erosion exceeding 30 cm below the estimated post-construction tread surface was observed at 734 locations, at 100 of which the depth exceeded 61 cm (Table 3). A total of 24 km of trail (4.6% of the sample) had soil erosion exceeding 30 cm. On average, 46 m/km of trail had at least this much soil erosion for an average of 326 m per trail. Excessive root exposure was observed at 365 locations, affecting 3.9 km of trail and 1% of the surveyed trails.

Running water, wet soils, and rutted treads were amongst the leading contributors to excessive tread width, for this impact was typically caused by trail users seeking to avoid poor or treacherous trail conditions in the main tread. Tread widths exceeding 90 cm wider than is typical for adjacent treads were observed at 176 locations, affecting 3.6 km of trail and 0.7% of the surveyed trails (Table 3). Multiple treads, another form of trail expansion typically caused by trail users travelling abreast or seeking to circumvent poor trail conditions (Hammitt & Cole 1998), were common on the surveyed trails. A total of 470 occurrences of multiple treads (two or more) were observed. As measured on the main tread, 10.3 km of parallel multiple treads were recorded, affecting 1.8% of the surveyed trails.

In spite of a drier than average summer, wet soil was the most common form of tread problem, which may often lead to excessive trail widening. Seven hundred and fifty-two occurrences of wet soil incidents were recorded with an aggregate lineal extent of 18.2 km. On average, there were 1.4 incidents and 35 m of wet soil existed on every km of the surveyed trails (Table 3). Running water on trail was less frequent with only 227 occurrences, affecting a total of 4.2 km of all trails surveyed.

Design and maintenance data

A total of 4137 drainage dips were observed, averaging 7.8 per km (Table 3). Water bars were employed only slightly less frequently; 3804 were observed, averaging 7.2 per km. Combined, there were 7941 tread drainage features, an average of 15 per km. A larger percentage of water bars (44%) were judged to be very effective, compared to 20% of drainage dips (Table 3). Conversely, a greater percentage of drainage dips (43%) were judged to be ineffective, compared to 33% of water bars.

Spatial relationships

The spatial distribution of trail problems could be evaluated at the park-wide level. Serious tread impact problems were well distributed throughout the Park's trail system (Fig. 5). However, somewhat higher concentrations of tread problems occurred in the central and eastern portions of the Park. In particular, six of the ten muddiest trails (i.e. having a wet soil problem) were clustered in the Cataloochee area, which is situated in the eastern portion of the Park. Relatively few trails had significant deterioration for several different types of impact (Fig. 5). Only two trails were ranked amongst the ten poorest for as many as four types of impact.

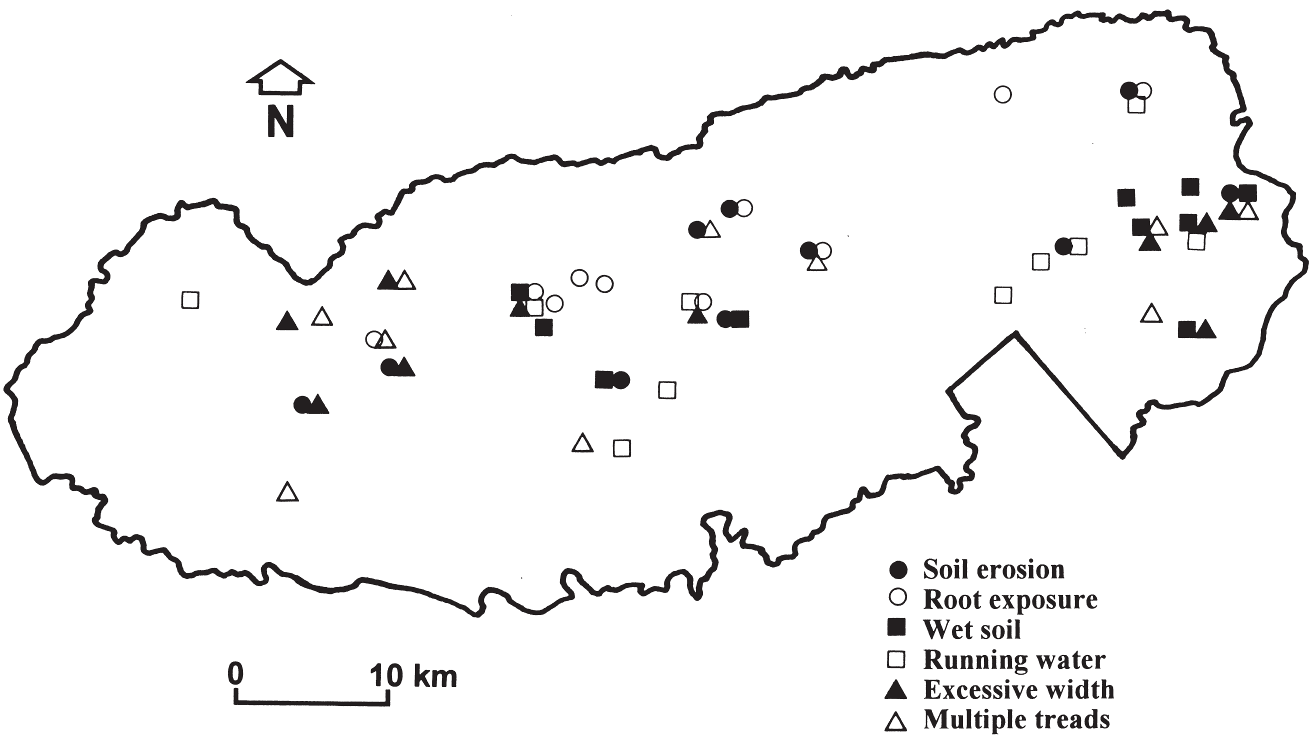

Figure 5 Spatial distribution of trails that rank amongst the ten poorest in the lineal extent (m/km) of one or more types of impact problem.

Discussion and management implications

This paper has presented a problem-oriented trail IA&M method, the TPAM, and its application in a high-use national park in the USA. Procedures involved in the TPAM were efficient, requiring one or two staff to push a measuring wheel at normal walking speeds, only stopping as needed to record the locations of tread problems or maintenance features. This assessment approach is applicable to localities other than protected areas, and to other linear features, such as tracks created by snowmobiles and all-terrain vehicles. The selection of indicators and their definitions may also be adapted to different environmental conditions, trail degradation problems, or management needs in other protected areas. The TPAM yielded quantitative information that was useful to Park managers in three major ways:

(1) Tabular and graphic presentations of survey results could characterize different trail segments in terms of their location, length, resource or impact conditions, and maintenance features. Managers may find this information valuable in preparing and justifying trail management actions, maintenance budget and staffing requests. Data on individual trails might also be used to direct trail maintenance activities or to set priorities for needed work;

(2) Analysis of survey data may identify relevant environmental, managerial and use-related factors that influence trail conditions. Managers may find this information valuable in improving trail planning and management decisions, such as selecting resistant and resilient locations for new or re-routed trails, or managing the amount and type of trail use to match resource capabilities; and

(3) Replication of trail surveys would provide a monitoring function, documenting changes in trail conditions over time. Analysis of data from different monitoring cycles can reveal trends in trail conditions and evaluate the effectiveness of implemented management actions. This function is integral to the successful application of contemporary park planning and management decision-making frameworks such as the Limits of Acceptable Change (Stankey *et al.* 1985) and the Visitor Experience and Resource Protection (National Park Service 1997*a*).

Results from this study showed a high concentration of wet soil problems in the Cataloochee area on the eastern portion of the Park. A similar spatial clustering of muddy trails in this area was reported by Bratton *et al.* (1977*a*, *b*) in their survey of the same park. Such a pattern may be explained by a combination of two major factors. First, many trails in the Cataloochee area were not well designed, closely paralleling streams on poorly drained organic soils. Trail treads often become embedded in the flatter valley bottom terrain and remain wet throughout the summer. Second, most of these trails receive high horse use, which has been shown to cause greater impacts on trail treads (Nagy & Scotter 1974; McClaran & Cole 1993).

Survey results also demonstrated that few trails suffered from more than one or two types of tread problems. An implication is that many different, and to some extent, unique, sets of factors contributed to various types of tread problems. This is supported by examination of any single trail, which while receiving approximately the same amount and type of use, often exhibits segments in good condition as well as segments in poor condition with respect to many different types of tread problem. Analyses of survey data revealed that tread problems were related to both environmental and use-related factors (Marion 1994). For example, all muddiest trails occur in flat valley bottom terrain where treads become embedded in moist organic soils. Such trails can often sustain limited hiking use, particularly during the drier summer months. However, heavy foot or horse traffic, particularly during wetter periods, can quickly lead to excessive tread muddiness and widening as visitors seek to circumvent muddy treads and standing water.

Assessment results of trail design and maintenance features suggest that water bars are more effective than drainage dips in diverting water off trail treads. However, factors such as the relative ages, quality of installation, and maintenance of the tread drainage features, as well as the subjectivity of our ratings, made it difficult to derive any definitive statements about relative effectiveness.

Information from this survey has already been applied in both trail planning and management decision-making in GSMNP. For example, survey results have been incorporated into strategic planning (National Park Service 1995) to provide an appraisal of the Park's trail conditions, and to serve as the basis for formulating management strategies and actions. Results from relational analyses have also been communicated to Park staff in order to help them understand the influential factors of tread impacts, and to suggest and evaluate alternative management interventions (Marion 1994). Future replications of the present survey were recommended in the backcountry recreation plan (National Park Service 1995).

A number of limitations of the TPAM were revealed. First, this method did not provide data for characterizing *average* tread conditions. For example, no data on mean tread width or depth could be gathered. Second, the use of predefined tread problems presented field staff with the difficulty of deciding when observed tread conditions met the criteria required for assessment. Tread problems rarely began and ended abruptly, and sometimes they developed gradually from imperceptible to substantial degrees over a considerable distance. Staff had therefore to employ judgement in determining if tread conditions warranted recording, and if so, precisely where to begin and end each problem segment. Third, use of predefined problems required staff to employ a minimum lineal distance over which a tread problem manifested itself (3 m in this survey). Reducing this minimum distance may yield more accurate data on the extent of some indicators but could also greatly increase field assessment time.

In summary, the TPAM is proposed as an efficient trail IA&M survey method that yields a variety of quantitative data that are of management utility. These data can characterize the frequency and extent of trail impact problems and document their locations to guide maintenance responses. However, the judgements required by field staff in determining whether and precisely where the targeted tread problems occur along a trail raise questions regarding the precision of this method. Research is needed to evaluate the precision of this trail survey method relative to that of alternative methods. Such work is particularly critical if this method were employed to monitor trail degradation over time and used as a basis for evaluating trail condition standards and decision-making.

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