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Source: Mountain Research and Development, 30(4):332-343.
Published By: International Mountain Society
https://doi.org/10.1659/MRD-JOURNAL-D-09-00078.1
URL: http://www.bioone.org/doi/full/10.1659/MRD-JOURNAL-D-09-00078.1

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Mountain Research and Development (MRD)
An international, peer-reviewed open access journal
published by the International Mountain Society (IMS)
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Assessment and Monitoring of Recreation Impacts and Resource Conditions on Mountain Summits: Examples From the Northern Forest, USA

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Mountain summits present a unique challenge to manage sustainably: they are ecologically important and, in many circumstances, under high demand for recreation and tourism activities. This article presents recent advances in the assessment of resource conditions and visitor disturbance in mountain summit environments, by drawing on examples from a multiyear, interdisciplinary study of summits in the northeastern United States. Primary impact issues as a consequence of visitor use, such as informal trail formation, vegetation disturbance, and soil loss, were addressed via the adaption of protocols from recreation ecology studies to summit environments. In addition, new methodologies were developed that provide measurement sensitivity to change previously unavailable through standard recreation monitoring protocols. Although currently limited in application to the northeastern US summit environments, the methods presented show promise for widespread application wherever summits are in demand for visitor activities.

Keywords: *Mountain recreation; visitor impacts; recreation impact monitoring; recreation ecology; mountain summits; USA.*

Peer-reviewed: *May 2010* ***Accepted:*** *May 2010*

Introduction

Mountain tourism and recreation has often been seen as a vital and desirable way to sustain mountain communities and provide incentives for protecting montane resources, including sensitive flora and fauna. Recent work suggests that there has been a rise in the popularity of mountain recreation and tourism and, as such, an increase in the potential for associated ecological impacts to mountain ecosystems (Godde et al 2000; Nepal and Chipeniuk 2005; Geneletti and Dawa 2009). Consequently, there has been considerable interest in applying sustainable development and visitor management strategies in mountain regions that allow for the advancement of local economies while offering protection of the cultural and ecological base upon which tourism depends (Crabtree and Bayfield 1998; Price and Kim 1999).

Although visitation and resource condition trend data for mountain ecosystems worldwide are rare, both anecdotal information and related trend data are suggestive of increased demand and ecological impact in mountain regions. Worldwide, participation in recreation and tourism in protected areas continues to grow, although currently no global tabulation of protected area usage is available (Eagles and McCool 2002; De Lacy and Whitmore 2006). Similar trends of increasing demand for recreation and tourism opportunities have been reported in mountain areas worldwide, including the mountain regions of Australia, New Zealand, and Nepal (Booth and Cullen 2001; Nepal 2003; Pickering and Buckley 2003). Tourism is the world's largest and one of its fastest growing industries, with worldwide tourism receipts reaching US$ 680 billion in 2005 (UNWTO 2007). It has been estimated that mountain areas are host to 15–20% of the tourism industry (FAO 2005). Tourism in mountain areas often entails outdoor recreational activities, such as hiking, backpacking, climbing, skiing, and mountaineering. This growing visitation to fragile mountain parks and summits is of importance to managers concerned with sustainable management of visitor use.

Concurrently, ecological assessments of the consequences of recreation and nature-based tourism activities suggest that impacts are widespread and increasing, and are becoming a worldwide management concern (Hammitt and Cole 1998; Newsome et al 2002;

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Monz et al 2010). In these contexts, land managers are often faced with contradictory management goals: permitting visitor access while simultaneously preserving the naturalness and pristine character of area resources. Recreation impacts in high elevation ecosystems can be particularly problematic, because summit ecosystems are often unique and sensitive, harboring isolated "islands" of biodiversity that occur infrequently. Moreover, these ecosystems often include rare montane flora and fauna adapted to survive in rocky infertile substrates, extremely short growing seasons, and harsh climates (Emanuelsson 1985; Grabherr 1985; Price 1985).

Management of summit resource impacts is also challenging, because trampling impacts to vegetation and soils can occur quickly, and recovery rates are extremely slow (Grabherr 1985; Price 1985). Furthermore, the spatial scale of recreation traffic can be nearly the full extent of summit ecosystems, in contrast to other ecosystems where the spatial extent of recreation impacts have affected less than 1.5% of protected natural areas (Cole et al 1997). Finally, mitigation actions are frequently limited to hardening and rehabilitation of trails and sites, logistically difficult and expensive actions at summit locations.

Although studies have examined the effects of trampling on alpine vegetation (eg Cole and Monz 2002; Willard et al 2007), we note that only a few studies have investigated recreational use patterns and impacts specific to high-elevation summits (eg Ebersole et al 2002; Pickering and Buckley 2003), and none have examined impact assessment and monitoring protocols. Protected area managers require objective protocols to document impacts and evaluate trends associated with visitor travel to summits and at summit destination sites. For example, hiking impacts associated with travel to summits are rarely limited to 1 or 2 designated trails; impacts from a proliferation of informal (visitor-created) routes are a common and significant impact management problem. Upon attaining a summit, visitors often disperse, which extends trampling impacts to all available usable terrain, with the potential for extensive trampling damage to summit area substrates and vegetation.

The objective of this article is to report on the development and application of several different approaches for assessing and monitoring recreation resource impacts on mountain summits. The authors and colleagues have been engaged in a multiyear program of research that examines the social and ecological aspects of recreation and tourism use of mountain summits in the Northern Forest, US (Park et al 2008; Goonan 2009; Goonan et al 2010). In this region, the demand for mountain recreation is exceptionally high, and, although there are numerous summits accessible via hiking and a few accessible to vehicles, the total spatial extent of summit ecosystems is very limited. In the course of this research, we modified and advanced existing recreation ecology protocols and developed new approaches to assess the trajectory of change on summit areas where recreation use is prevalent. To accomplish our article's objective, we present methodologies and illustrative results from this research program and offer commentary on additional methods development needs.

Study sites

The Northern Forest

The Northern Forest is the largest intact forest ecosystem east of the Mississippi River in the United States. It covers an area of nearly 30 million acres and extends from the western border of New York State to the eastern border of Maine. Vast forests, critical habitat for numerous plant and wildlife species, and the headwaters of several major rivers are contained within the region. The area is home to approximately 1.5 million permanent residents and receives nearly 10 million visitors annually (Northern Forest Center 2008). Outdoor recreation and tourism are important, traditional uses of the Northern Forest, and the vast areas of undeveloped land provide for a wide variety of recreational opportunities. Mountains are widely distributed throughout the Northern Forest region with more than 100 summits that exceed an elevation of 1200 m (Northern Forest Center 2008).

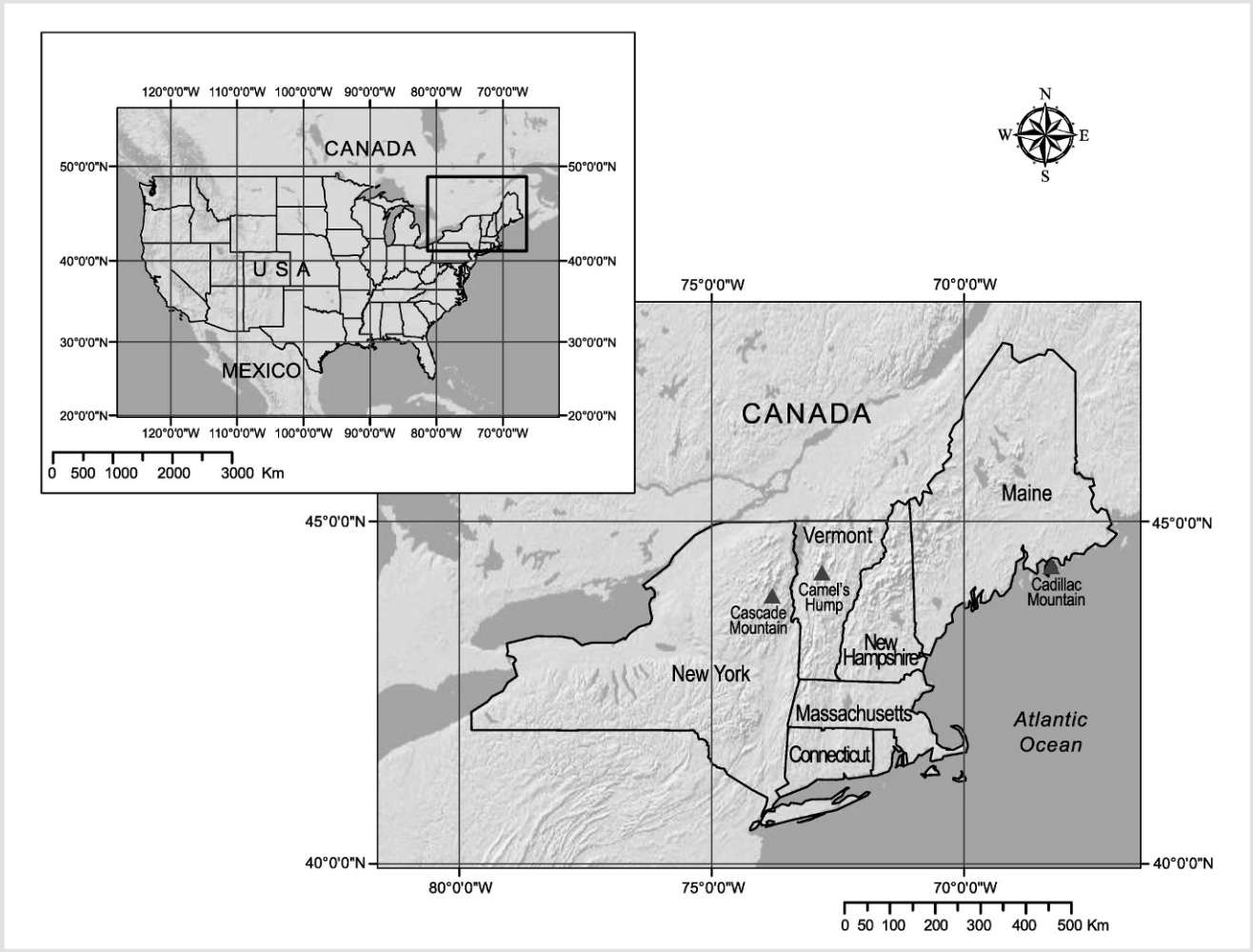
Site selection and summit study areas

Three summits (Figure 1, Table 1) were chosen as study areas via an extensive classification process to determine mountains representative of the current continuum of resource, managerial, and visitor experience conditions (see Goonan 2009 for details). Cascade Mountain in New York was chosen to represent the primitive end of the spectrum, with relatively low levels of development, recreation activity, and management presence. Cadillac Mountain in Maine was chosen to represent the developed end of the spectrum, which represents relatively high levels of site management, recreation activity, and management presence. Camel's Hump in Vermont was chosen to represent the middle of this spectrum. Although the ecological assessment methods described in this article were applied to all 3 summits, the examples from Cascade Mountain and Cadillac Mountain best illustrate the techniques, and, therefore, we focus on these summits for the remainder of the discussion.

Methods

To inform our development of summit condition assessment and monitoring methods, we conducted site visits to approximately 20 summits in the Northern Forest during the 2007–2008 summer season. In the course of this scoping work, we documented the nature and type of observable resource impacts present on the summits. These observations, combined with discussions with land

FIGURE 1 Locations of study sites in Northern Forest, USA. (Map by K. Goonan)



managers, allowed us to identify 4 main recreation impact issues, as follows, that required protocol development in summit-based impact assessment and monitoring programs.

Informal trails and sites

Site visits revealed that mountain summits frequently have linear and nodal areas of intensive trampling disturbance that result from visitors hiking off formal (official) trails and sites to access mountain summits and vistas, or for exploration and other reasons. Managers reported that the proliferation of informal (visitor-created) trails is a common problem that contributes substantial trampling impact to fragile vegetation and substrates. Observations also revealed that summit visitation frequently results in the trampling of substrates and vegetation in nearly all available flat areas and vista sites. Assessing the conditions of these informal trails and sites are particularly important in mountain summit ecosystems because of their limited spatial extent, fragility, and potential for permanent and irreversible vegetation and substrate loss.

To assess conditions on informal recreation sites, we primarily relied on adapting recreation ecology assessment techniques developed for formal campsites (eg Marion 1995; Monz 2000; Newsome et al 2002). For each summit, an assessment area was mapped and foot searches identified all recreation sites, defined as nodal areas of visually obvious substrate disturbance created by visitor use. The size of each site was assessed by using the radial transect method (Marion 1995); a permanent reference point was recorded with a Trimble® GeoXT global positioning system (GPS) device and Hurricane antenna, and area calculations and geographic information system (GIS) coordinates were determined by Excel spreadsheet calculations. All GPS data were postprocessed by using Trimble's Pathfinder Office software to obtain submeter accuracy. Vegetation cover and soil exposure were evaluated on-site and in adjacent undisturbed controls as the midpoint value of 6 cover

TABLE 1 Attributes of mountain summits included in the study.

Summit	Management strategies	Types of access	Annual visitation[a)]	Elevation (m) and coordinates	Ecosystem type	Summit area (m^2)
Cadillac Mountain	Designated trails Ranger presence Informative signs Fencing	Hiking trail Paved road	2.1 M[b)]	466 44°13′N 73°51′W	Subalpine	71,020
Camel's Hump	Designated trails Ranger presence	Hiking trail	15,000–20,000[c)]	1243 44°19′N 72°53′W	Alpine meadow	5336
Cascade Mountain	Designated trails Informative signs	Hiking trail	12,000–14,000[d)]	1249 44°21′N 68°13′W	Subalpine	7606

[a)] Annual visitation based on best available data provided by the following sources.
[b)] Turner and LaPage 2001.
[c)] Paradis 2003.
[d)] Goren 2009 personal communication.

classes (Marion 1995). Assessments of the number of trees and shrubs with damage, root exposure, and assessments of litter and trash also followed Marion (1995). Digital photos were taken to document impacts and to aid in site relocation.

Assessing informal trail networks on mountain summits was more challenging because the terrain is often dominated by barren rock, and informal trails are readily apparent only on soil substrates. Thus, informal trails in summit environments are frequently discontinuous and short, increasing the difficulty of locating and documenting the trail fragments and evaluating their condition. Although airborne remote sensing techniques are possible (Witztum and Stow 2004), they require expensive high-resolution imagery and complex analytical processing that place this option beyond the means of most land managers. The narrow fragments of informal trails and areas of lighter impact are also difficult to distinguish on aerial imagery. Application of point sampling or problem assessment methods traditionally applied with measuring wheels to assess formal trails (Marion and Leung 2001) were also ruled out because of the difficulty of applying them to widely spaced, discontinuous informal trail fragments.

The increasing accuracy of professional grade GPS units led to their application in census mapping the informal trail fragments within each study area, as reported in similar surveys by Leung and Marion (1999), Bacon et al (2006), and Marion et al (2009). We used the GeoXT GPS device and careful foot-based searching within each study area to map the locations of all informal trail segments. Two informal trail condition attributes were assessed during field collection, as described in Marion et al (2009): condition class (CC) ratings on a 1–5 scale (Table 2), and an assessment of average tread width (TW). A new informal trail segment was designated and assessed when a consistent change in CC or width was noted in the field.

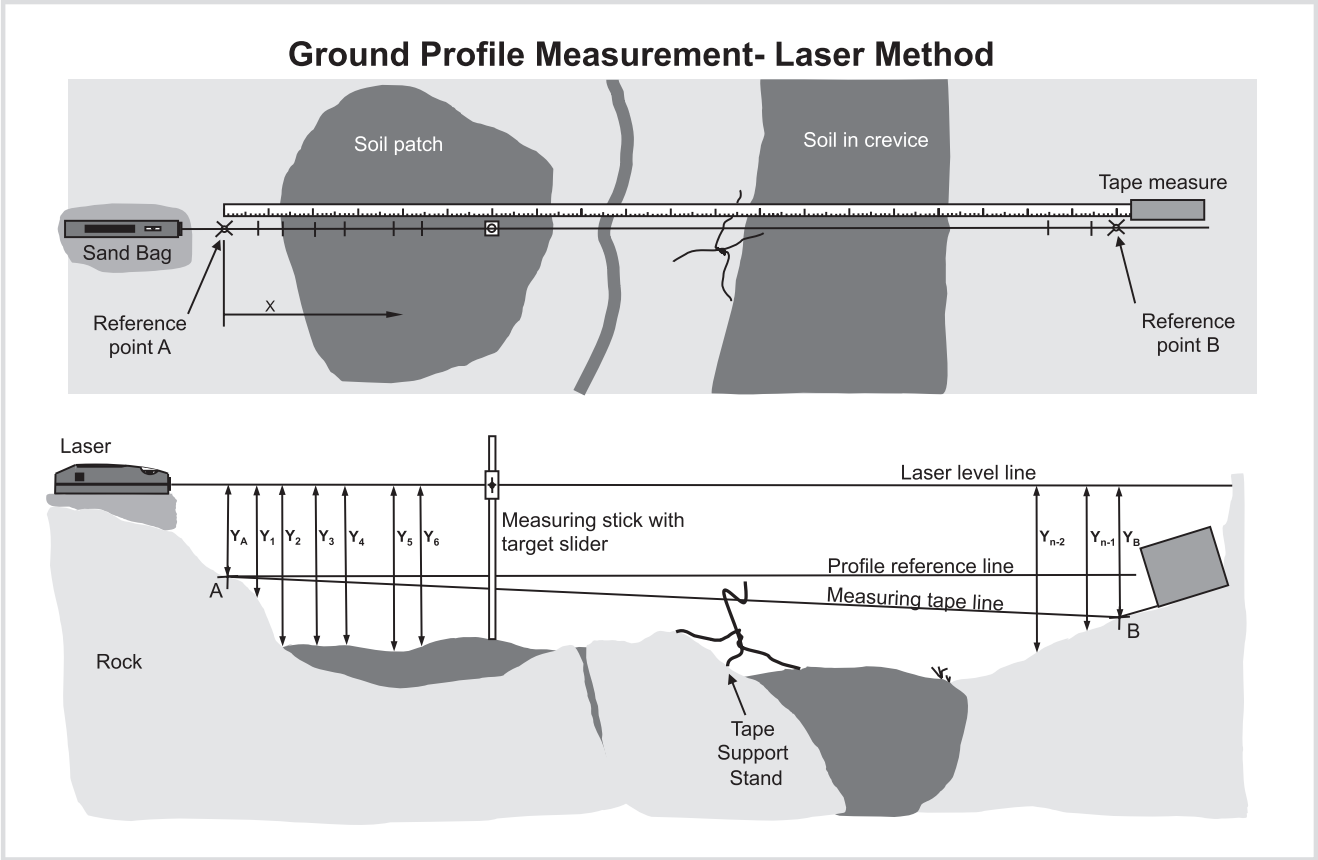
Summit land cover assessment

A quadrat-based, image analysis sampling technique (Booth et al 2005; Seefeldt and Booth 2006) was adapted and applied to measure vegetation and ground cover within the summit areas. This procedure involved 3 field

TABLE 2 Unofficial trail condition class definitions for mountain summits.

Condition class	Definition
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 primary use areas
3	Vegetation cover lost and/or organic litter pulverized within the center of the tread, some bare soil exposed
4	Nearly complete or total loss of vegetation cover and organic litter within the tread, bare soil widespread
5	Soil erosion obvious, as indicated by exposed roots and rocks and/or gullying

FIGURE 2 Accurate assessments of substrate profiles with a laser referenced to permanent features. (Design by C. Carr)



components: (1) identification and mapping of zones of possible recreation use within the summit area, (2) creation of a stratified random grid of sampling locations by using ArcGIS 9.3 software, and (3) navigation to sample locations with the GPS and to obtain digital images of 1-m^2 quadrats for subsequent image analysis of ground-cover classes.

Summit area zones of possible recreation use were mapped by using the GPS, and summit polygons were uploaded to ArcGIS (ESRI, Inc, Redlands, CA, USA). We defined these summit areas by several factors, including topographic limitations to recreation use, such as steep terrain and cliffs, thick vegetation, and krummholz boundaries that limit visitor use; and the observable limit of soil and vegetation disturbance from recreation use. A statistical power analysis was conducted (alpha = 0.05; beta = 0.10) to determine the number of quadrats needed for each mountain based on the area of the summit polygon and an estimate of vegetation-cover variance derived from an analysis of satellite images. Hawth's Analysis Tools extension for ArcGIS (Beyer 2007) was used to create a random grid overlay on each summit polygon. Quadrat photos were taken with a Nikon COOLPIX P50 8.1-megapixel digital camera mounted onto a frame with a 1-m^2 base that positioned the camera for nadir (overhead perspective) images 1.4 m above ground level. Measurements from digital images were used to quantify the relative cover of ground cover types by using SamplePoint software (Booth et al 2006). Eleven ground-cover classes were included in the classification of mountain summit land cover, including graminoids, shrubs, forbs, ferns, crustose lichens, foliose lichens, organic soil, mineral soil, bedrock, organic litter, and standing dead wood.

Soil loss monitoring

Scoping visits to many summits revealed areas of exposed mineral soil where recreational traffic had removed vegetation cover and soils, a substantial management concern given the limited soil development and vegetation cover in summit environments. We developed a laser-based transect method for accurately measuring cross-sectional substrate profiles from fixed permanent reference points (Figure 2), established by drilling small-diameter (3-mm) holes at transect end points established in adjacent bedrock. This methodology uses a projected laser-level beam to establish a reference line at a known elevation above areas with exposed soils, with a series of vertical measurements at fixed intervals along each

TABLE 3 Summary of informal trail assessment for Cadillac Mountain.

Condition class	No. segments	Total length (km)	% Total length	Total area affected (m^2)	% Total summit area	% Total summit vegetated area
1	39	0.21	8.17	87.48	0.12	0.44
2	40	0.30	11.67	152.91	0.22	0.76
3	91	0.67	26.07	388.82	0.55	1.94
4	87	0.81	31.52	655.88	0.92	3.28
5	78	0.58	22.57	445.97	0.63	2.23
Total	**335**	**2.57**	**100**	**1731.06**	**2.44**	**8.65**

transect to substrate surfaces, with subsequent cross-sectional area calculations to a profile reference line. Soil loss and/or gain over time can be computed through comparisons with transect data from subsequent monitoring cycles.

Soil profile transects were purposively located on soil patches bordered by bedrock because of constraints imposed by the need to establish permanent reference points. Notwithstanding this limitation, our goal was the selection of representative transects within different zones of visitor access. For example, on Cadillac Mountain, 7 transects were established in areas of high visitor use, 4 transects in off-trail areas open to visitor traffic, and 3 transects within fenced exclosures that discourage visitor access.

Spatial patterns of visitor use

A final component of our research sought to document actual spatial patterns of visitor traffic on summits. Understanding the spatial distribution of visitor use is important from 3 perspectives. First, when combined with the assessments of vegetation and soil condition, spatially explicit information on the extent and density of visitor use allows for the determination of areas where use may be a factor in resource change. Second, such data provide information on the effectiveness of current management strategies at confining visitor use to designated trails and sites, strategies frequently used to limit resource damage. Third, such data provide insights for understanding visitor behavior regarding summit access routes and locations most frequently used by visitors. Managers can use this information to evaluate if additional system trails and hardened sites are needed to sustain visitation while protecting sensitive summit resources.

In an exploratory study on the Cascade Mountain summit, spatial patterns of visitation were determined by giving Garmin GPS Map 60 receivers to 105 visitors randomly intercepted along the formal summit access trail on 8 days over a 2-month, summer period. Visitors wore the GPS devices clipped to their backpack and were asked not to alter their behavior in any way. The GPS units were set to record a "tracklog" of location points at 5-second intervals, which were uploaded to ArcGIS for subsequent analyses of spatial patterns.

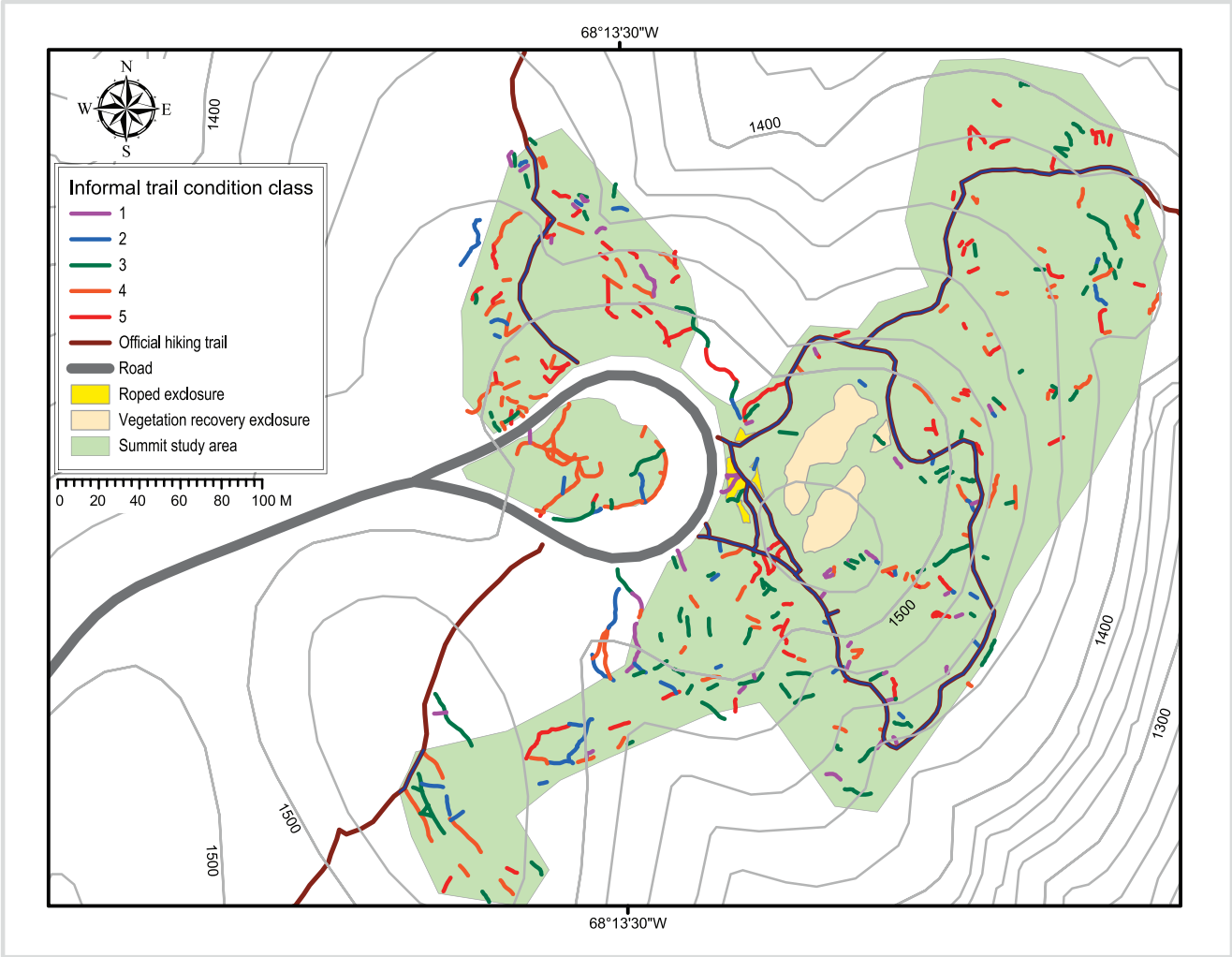
Results and discussion

Assessment of visitor-created trails

Cadillac Mountain illustrates the resource protection concerns associated with high off-trail use as visitors disperse to areas away from the formal trail system. In spite of an adequate formal trail network that consists of 2 summit access routes that connect to a paved circular summit trail with formal observation sites, we found 335 informal trail segments, which total 2.57 km within the summit study area (Figure 3). The informal trails were discontinuous fragments, which occur on vegetated shallow lenses of soil separated by areas of bedrock. To offer some perspective, the visitor-created trail network on the summit of Cadillac Mountain is 2.5 times longer than the total length of designated trails in the summit area. Informal trails ranged in width from 20–213 cm, with a mean of 63 cm. The condition of informal trails was generally poor, with 80% of their total length classified as CC 3–5, which indicates substantial vegetative cover loss and soil exposure/erosion (Table 3). Within the summit study area, informal trail treads directly affected 1731 m^2, which represent 2.4% of the total summit area and 8.7% of the vegetated summit area.

In the Northern Forest, these informal trail impacts can be particularly acute, because subalpine and alpine plant communities on mountain summits are typically fragile, spatially restricted, and rare (Ketchledge et al 1985). The unstructured nature of recreation visitation in most summit environments is a particular cause for concern; visitors frequently venture off formal trails to follow one of many informal routes to and from summits. Guidebooks frequently present an array of ascent options, many of which are not formal trails. Such multiple routes can represent challenges to managers, given their resource protection mandates. Observations and discussions with

FIGURE 3 Map of trail network on summit of Cadillac Mountain. (Map by K. Goonan)



managers also revealed the difficulties that visitors have in determining which trails are formal, because hikers frequently erect rock cairns to mark informal routes.

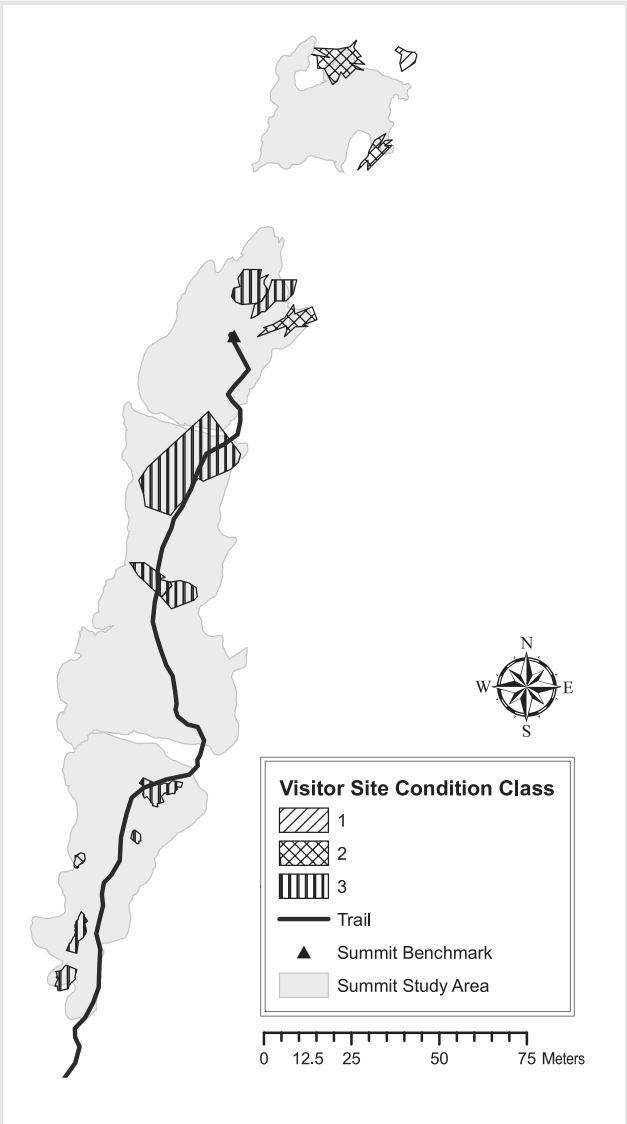
Informal trails are a significant management concern and a commonly reported resource protection issue in recreation ecology impact assessment studies (eg McEwen et al 1996; Thurston and Reader 2001; Nepal and Nepal 2004). Because informal trails are not planned or constructed, they are frequently poorly located with respect to terrain and resource protection needs, and their proliferation over time increases habitat fragmentation and resource impacts to sensitive ecological communities (Marion et al 2006). From a visitor-experience perspective, informal trails create a visually scarred landscape, particularly above the tree line (Marion et al 2006). These concerns can be addressed through the assessment and monitoring of informal trail conditions, which provide important indicators of human impact in summit ecosystems for assessing the efficacy of management actions intended to protect them. Because of their ecological, social, and managerial significance, informal trail attributes have also been used as indicators in carrying capacity planning and management frameworks (Bacon et al 2006).

Visitor-created sites

Cascade Mountain illustrates issues associated with the development of visitor-created sites: discrete areas of concentrated off-trail trampling impact (Figure 4; Table 4). These activities result in observable, continuous areas of disturbance, analogous to visitor-created campsites in backcountry areas. We note that summit and vista sites are rarely designated or have clearly marked boundaries.

On Cascade Mountain, we observed 14 sites, with mean vegetation cover loss of 23% and 10% mineral soil exposure. The aggregate area of trampling disturbance for these sites was 961 m^2, which affects approximately

FIGURE 4 Visitor created sites on Cascade Mountain summit. (Map by K. Goonan)



62% of the summit's vegetated area. These results suggest the need to designate formal vista sites in nonvegetated areas with discrete boundaries (eg scree wall borders).

Summit land cover and susceptibility mapping

Analysis of the quadrat-based sampling on Cadillac Mountain shows the summit land cover to be high in crustose lichens (46%), with remaining cover distributed among shrubs (15%), bare rock (14%), exposed mineral soil (8%), graminoids (7%) and forbs (5%), and other classes each accounting for less than 1% cover (Table 5). These land-cover types exhibit differential tolerance to recreation disturbance from trampling (Cole 1995a, 1995b), so relative changes in cover classes over time are a sensitive indicator of summit-wide resource change because of recreation disturbance.

Soil-loss monitoring

Results of the soil profile assessments document the vertical distance between the soil surface and permanent reference transect lines (Figure 5). This procedure establishes an accurate and repeatable method for examining soil-profile changes over time, with repeated assessments that document subsequent soil loss or gain.

Soil loss is an important aspect of recreation disturbance to natural areas, and many studies of both trails and campsites include estimates of soil loss. Soil loss is particularly critical in subalpine and alpine environments because of slow rates of soil development and the necessity of soil for plant growth. Recent advances in trail impact monitoring have included improved measurement procedures for examining the depth of incision along trails and for assessing volumetric measures of soil loss by using a cross-sectional area method (Olive and Marion 2009). The procedure developed here is a more accurate and sensitive version of the cross-sectional area measurements applied to trails.

Spatial patterns of visitor use

Our experimental study to document summit visitor-use distribution patterns with recreation grade receivers found measurement errors to be minimal, (approximately 3 m) because of optimal satellite reception and the relatively high accuracy of the GPS units used. Analysis of GPS visitor-tracking data on the Cascade Mountain summit (Figure 6) reveals substantial off-trail traffic. Although much of the off-trail traffic occurred in the vicinity of the formal access trail, tracking revealed several nodal areas of concentrated use and activity in areas north of the summit. Such data can be used to inform the selection of a subset of formal summit recreation sites.

With respect to trails, this summit is atypical in having just 1 formal trail. For summits with multiple formal and informal trails, a similar study would be more challenging but could provide important data that inform managers faced with decisions related to selecting and managing formal trails, or discouraging the use of informal trails. Assessment of visitor-use data in the spatially explicit fashion shown here allows managers to better understand and manage typical use patterns and could provide early warning of use in sensitive locations.

Conclusions

This study presented selected results from the application of a variety of mountain summit trail, recreation site, and area-wide condition-assessment methods. Such assessments can be used to characterize summit resource conditions and recreation-related impacts, and long-term trends when reapplied over time. Such data can also be used to select and evaluate the success of summit visitation management actions and applied to carrying-capacity decision-making frameworks. Although a

TABLE 4 Summary of visitor sites on Cascade Mountain summit.

Impact parameter assessed	Cascade summit area
No. sites	14
Condition class[a)]	2.6 ± 0.7
Vegetation cover loss (%)[a)]	23.3 ± 5.6
Mineral soil exposure (%)[a)]	10.9 ± 6.3
Soil erosion (1–3 rating scale)[b)]	2 ± 2
Root exposure (1–3 rating scale)[b)]	2 ± 2
Total area of sites (m^2)	961
Total summit vegetated area affected (%)	61.9

[a)] Values are means ± SE.
[b)] Values are medians ± range.

considerable literature exists on the assessment and monitoring of recreation resource conditions and associated impacts (eg Hammitt and Cole 1998; Leung and Marion 2000; Newsome et al 2002), heretofore, we know of few studies that have sought to adapt and apply these approaches to mountain summits. The work presented here illustrates an advancement of assessment and monitoring approaches in these sensitive and spatially limited environments. Subsequent applications of these techniques, and future modifications and advances in other mountain environments, are needed to perfect their application.

Because of the relatively small spatial scale and high intensity use that occur on the summits we examined, a high level of accuracy and precision was needed in the monitoring protocols applied. Consequently, the techniques we developed are labor intensive. For example, the quadrat method for assessing summit land cover was developed over other possible methods for several reasons. Our investigations on using remote sensing technology to measure land cover revealed several limitations. Recent applications of remote sensing on Cadillac Mountain (Kim et al 2007) demonstrated an ability to detect summit-wide vegetation changes over time but not changes along specific trails and recreation sites or at the plant-growth form level. Numerous recreation ecology studies have demonstrated the differential response of plant morphological types to recreation disturbance (eg Cole 1995a, 1995b; Hammitt and Cole 1998), so a sensitive monitoring system should be able to detect such changes over time. The method illustrated here has the ability to detect these changes, and, although not a component of our study, further refinement of the image capture and measurement technique may yield data at the plant-species level as

TABLE 5 Percent cover of vegetation, lichens, exposed soil, and bedrock on the Cadillac Mountain summit.

Land cover class	Cover (%)
Graminoids	7.10
Shrubs	15.50
Forbs	5.50
Ferns	0.02
Moss	0.58
Crustose lichens	46.30
Foliose lichens	0.09
Organic soil	0.50
Mineral soil	8.60
Bare rock	14.40

FIGURE 5 Example of a soil profile transect on Cadillac Mountain summit.

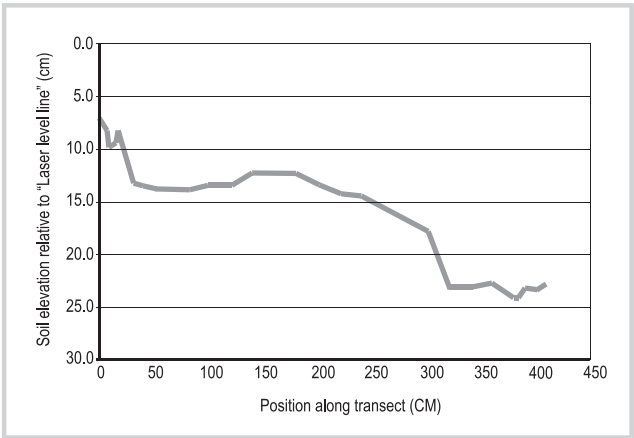
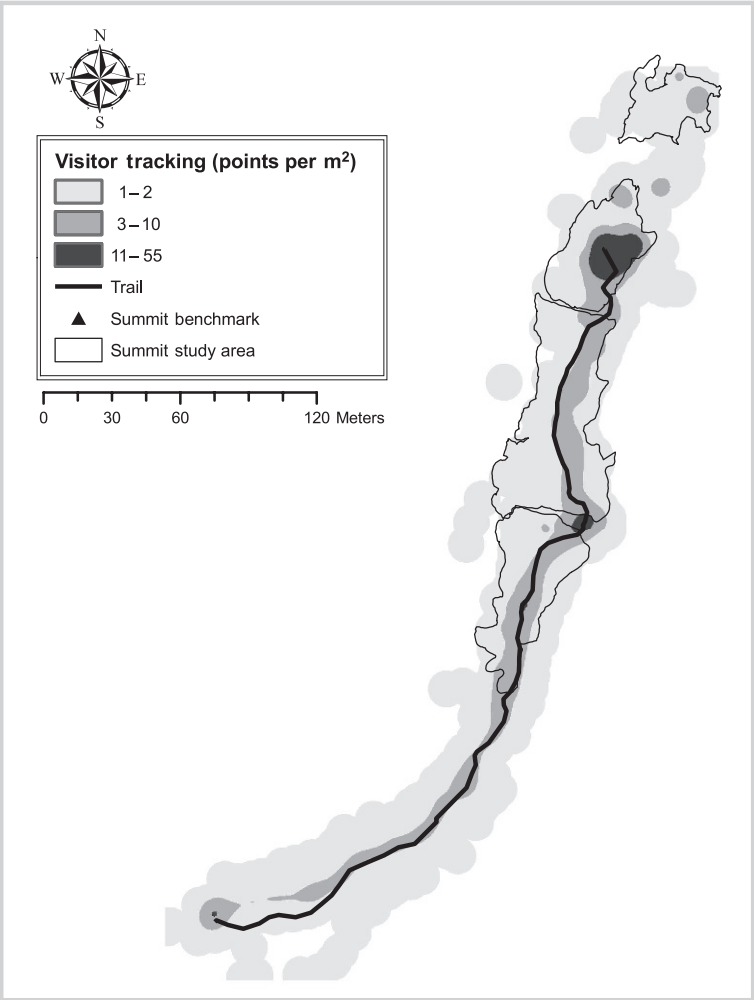


FIGURE 6 Visitor-use densities on Cascade Mountain. (Map by K. Goonan)



suggested by Booth et al (2006). We are currently engaged in additional analyses intended to advance the image capture and analysis procedures of this method.

The efficient and accurate measurement of soil loss on trails and recreation sites is challenging but soil loss, particularly on mountain summits, is ecologically significant, recovers very slowly, and is difficult to restore. The laser-based cross-sectional analysis method provides an accurate means for monitoring what are likely small annual losses in substrates that accumulate over longer time periods. The trade-off is that the method requires specialized equipment, drilled holes at transect end points that can be relocated, and a number of time-consuming measurements and calculations. As with all impact assessment methods, managers need to consider their unique situation in terms of resource sensitivity, visitation types and patterns, and associated impacts when making decisions regarding the types of information they need and the sensitivity of applied monitoring protocols. Improving technologies are making it easier to replace qualitative or subjective impact assessments with accurate measurements.

The methods presented here also strike a balance between measurement-based assessments and less objective assessments of observable resource impacts. We chose this balance because of the need to have information representative of both summit-wide ecological conditions and data specific to observable disturbances along trails and at recreation sites. For example, managers can use information on informal trail and visitor site proliferation and visitor-use patterns to make decisions about the need to designate formal trails and recreation sites in some areas and to curtail access in others. In contrast, the data provided by the summit land cover assessments provides a more generalizable long-term monitoring perspective that integrates recreation disturbance monitoring and long-term ecological change.

Some of the work presented here shows considerable promise for future development. The improved accuracy of inexpensive GPS units made possible the monitoring of visitor-use patterns reported here; higher accuracy units are becoming available and will allow greater monitoring capability. Further development of the GPS assessment of visitor-use patterns through integration with visitor-use modeling could provide a predictive model of dispersed recreation use. Integration of this work with techniques that model the relative trampling susceptibility of different plant morphological types could provide a spatially explicit, predictive model of the response of vegetation to various scenarios of visitor use. We are pursuing these refinements in our future research projects.

We acknowledge that the methods presented here are most applicable only to certain kinds of mountain summits, generally, subalpine to alpine, open summits that accommodate nontechnical, recreation use. Although the methods were developed and tested in the northeastern United States, we believe they are adaptable to a wide range of geographic areas. Future applications of these techniques will yield information important to land managers responsible for protecting these limited resources.

ACKNOWLEDGMENTS

The authors thank the Northeast States Research Cooperative and Acadia National Park for providing funding for this multiyear research effort. We also thank Lauren Chicote, Peter D'Luhosch, Charlie Jacoby, Peter Pettengill, and Logan Park for their considerable help in conducting the field measurements. The lead author also thanks the Utah Agriculture Experiment Station for providing additional support for this work. The use of trade, product, or firm names in this article does not imply endorsement by the US government.

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