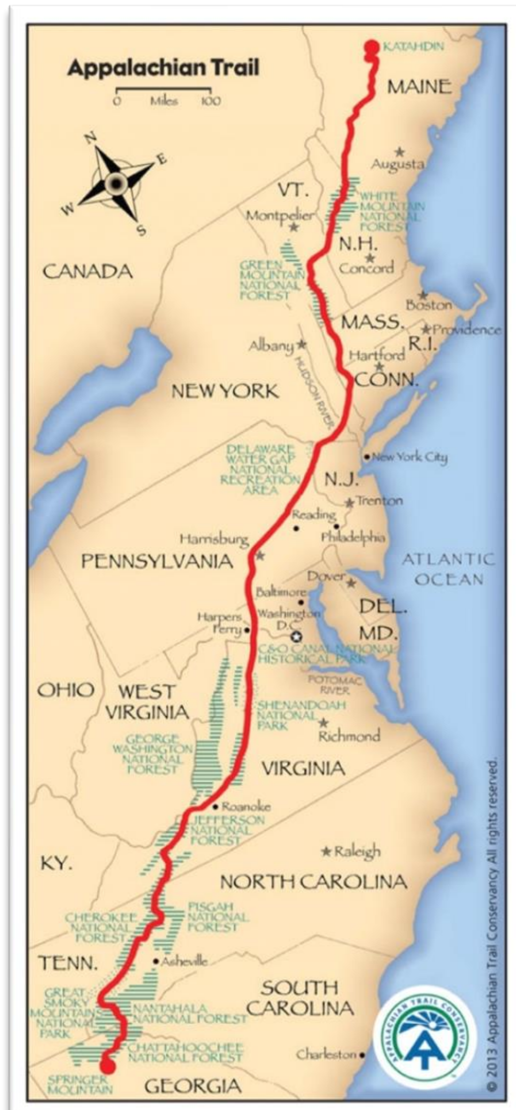
U.S. Geological Survey, Virginia Tech Field Unit

FINAL RESEARCH REPORT

Improving the Sustainability of the Appalachian Trail: Trail and Recreation Site Conditions and Management



Final Report, May 2020

Virginia Tech, College of Natural Resources & Environment

Department of Forest Resources & Environmental Conservation

Improving the Sustainability of the Appalachian Trail: Trail and Recreation Site Conditions and Management

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See also the companion document that is also a product of this research study:

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EXECUTIVE SUMMARY

The Appalachian National Scenic Trail (A.T.) is a unique internationally recognized protected natural area encompassing more than 250,000 acres and a 2,190-mile footpath from Maine to Georgia. A.T. management responsibilities are shared through a unique collaborative partnership between the National Park Service's Appalachian Trail Park Office (ATPO), the Appalachian Trail Conservancy (ATC), federal, state, and local land managers, and 31 volunteer trail clubs. The diverse array of latitude, elevation, and moisture gradients traversed by the A.T. contributes to a rich biological assemblage of flora and fauna, while also accommodating opportunities for more than three million visitors/year. The A.T. attracts local, regional, national, and international visitors, supporting day hikes, weekend backpacking and camping trips, section-hikes, and thru-hikes of the entire trail in a single year.

This research was funded by ATPO and administered by the ATC to accomplish the following core research objectives: 1) Provide quantitative, spatially-related, baseline documentation of the A.T. tread, informal trails, and recreation sites (overnight and day-use) to characterize the type, areal extent, and severity of visitation-related resource impacts to vegetation and soils, 2) Statistically analyze data to evaluate trail design and alignment attributes and recreation site biophysical attributes to develop sustainability models, ratings, and guidance, 3) Conduct analyses of tread and recreation site data to identify and describe the relative influence of key use-related, environmental, and managerial factors that can be manipulated through design and management actions to minimize resource and experiential impacts, and 4) Formulate Best Management Practices describing actions (educational/interpretive, regulatory, and site/facility management) that avoid or minimize resource and experiential impacts.

The Environmental Protection Agency's Generalized Random Tessellation Stratified (GRTS) sample design was applied to select a spatially-balanced and representative 9% sample that included 63 5 km (3.1 mi) segments that were assessed through early summer fieldwork from 2015-17. Within each segment field staff assessed A.T. tread conditions at 50 GRTS-sampled transects (N=3,150), measured all day-use and overnight recreation sites within a 150-meter (492 ft) corridor (N=731), and all informal visitor-created trails (22.8 mi). Measurement protocols published in peer-reviewed journals were applied to assess various physical, soil, and vegetative attributes of trail and recreation site resource conditions, along with many additional indicators assessed in the field or created during Geographic Information System analyses to support relational analyses and impact modeling.

This report begins with a Literature Review section that describe visitation-related visitor impacts and the primary factors that influence them. Experiential impacts, including crowding and conflicts, are also described as they are exacerbated in areas of high campsite density and use. Federal agency guidance related to managing visitor use, carrying capacity, and monitoring is also summarized, including research guidance for selecting monitoring indicators.

A Study Area section characterizes the A.T., it's resources, management, and bio-physical attributes. A Methods section reviews the research design, sampling methodology, and field assessment protocols applied in this study. The field manuals describing all field protocols are included in Appendix 2.

Based on a geographically representative 9% sample of the A.T., extrapolations of study data reveal that 708 acres, 0.28% of the approximately 250,000-acre A.T. corridor, are directly disturbed or impacted by visitor use. The largest percentage of impact (69%) is attributable to the 2,190-mi A.T. footpath, followed by overnight campsites (19%), informal trails (6%), and day-use sites (5%).

Summary of A.T. Tread Conditions

Baseline representative data for A.T. trail conditions describe the tread surface as predominantly organic litter (44%), soil (28%), and rock (16%), with some trail impacts represented by roots (2.4%) and mud (1.1%) (Table 6). Muddiness and roots were highest in the ATC NERO region (2.3% and 4.7%, respectively). These and other data can be used for comparison to future assessments to document longitudinal change and for establishing resource condition thresholds (standards) as part of carrying capacity and Visitor Use Management decision-making (Figure 3).

Trail science studies have revealed the significant influence of trail grade and trail slope alignment angle (TSA) for tread soil loss and trail widening so a recent Trail Sustainability Rating Index based on four categories of each variable was applied to the A.T. transect data. TSA refers to a trail's alignment to the prevailing landform grade, with fall-line trails significantly more vulnerable to soil loss than side-hill trails. The sustainability ratings indicate that 29.1% of the A.T. is rated "good," 18.1% "neutral," 31.6% "poor," and 21.2% is rated "very poor" (Table 10). Data also reveal that 11% of the A.T. has grades above 20% that are vulnerable to soil loss and widening, while 19% are in flat terrain (0-2%) and susceptible to trail muddiness and widening (Table 8). For "Poor" and "Very Poor" combined, NERO ranks as the least sustainable ATC region (62.3%), with the others ranging from MARO (39.0%), VARO (47.9%), to SORO (57.0%).

We note that the A.T. was originally laid out from 1923-37 with little regard to or awareness of modern sustainable trail design knowledge; much of the current A.T. alignment has been relocated from the original routing, and relocations, stonework, and bog-bridging have corrected many of the least sustainable alignments. These sustainability ratings can be used to identify the least sustainable A.T. sections for corrective actions, though many have either been addressed or have eroded to rock and are resistant to further impact. We note that glaciation removed much of the soil in NERO so steep or fall-aligned trails often erode to roots or rock.

Soil loss was assessed at A.T. transects as maximum incision, mean tread depth, and cross-sectional area (CSA), which can provide volumetric estimates of soil loss. Maximum incision ranged from 0-33.5 in with a median value of 2 (Table 12). NERO and SORO have the largest proportions of trail with more than 5 inches of incision (16.3% and 12.7%, respectively). CSA, calculated from numerous vertical measures along tread transects (Figure 7), ranged from 0-570 in^2 with a median of 32.2 in^2 (Table 13). Extrapolation to the entire A.T. provides an estimate of aggregate soil loss of 95,765 yd^3, or 7,980 standard 12 yd^3 dump trucks. Analyses revealed that in sloping terrain above 10%, maximum incision values increase as TSA values decrease (Figure 18), with the greatest incision values occurring on fall-line trails with landform grades exceeding 20%.

Trail width ranged from 0-197 in with a median of 22.2 in (Table 16). Just over half of the A.T. (58.6%) is 2 ft or less in width, while 15.2% exceeds 3 ft in width. Median trail widths increase from south to north, ranging from 20.3 in in SORO to 24.6 in in NERO. In NERO, wide trails are predominantly degraded fall-line trails and some high use segments through meadows; MARO's widest trails are often coaligned with woods roads. The low trail widths observed in SORO and VARO are due to their frequent side-hill alignments, which are substantially less susceptible to use-related widening. Statistical testing revealed no relationship between TSA and trail width on trails in flatter terrain (<15% landform grade) but significant widening occurs on fall-aligned trails in steeper terrain (Figure 19). Similar testing also correlated tread rugosity from rockiness and roots with significant tread widening (Figure 20).

Tread muddiness is caused by poor trail drainage and water retention. Muddiness is the rarest form of tread impact, ranging from 0-100% across transects with a median value of 0 (Table 17). Mud or standing water assessed as >20% of tread transects is present along 2.2% of the A.T., and bog bridging/boardwalks have been installed along an additional 1.1% of the A.T. (Table 20). Muddiness increases from south to north on the A.T. and was most prevalent in NERO, which had 55 transects with mud covering >20%, compared to 1 in SORO, 3 in VARO, and 11 in MARO. Field observations suggest that NERO has muddiness both in flatter terrain and along relatively level sections of side-hill trail. Vermont has the muddiest treads (13.0%), followed by Maine (7.5%), and New Hampshire (7.2%); the least muddy A.T. treads were found in Georgia, Maryland, and Connecticut (0.0%) and North Carolina and Tennessee (0.4%). While 69.7% of A.T. boardwalks were found in flat areas of 0-5% trail and landform grade, 33.6% of muddy transects (purposive and randomly selected) were found in areas with trail grades of 0-5% but landform grade of >5% (Table 22). Muddiness on contour-aligned side-hill trails in steeper terrain can be due to tread incision and/or the development of trailside berms and poor tread drainage but it's also best to avoid side-hill trails with level contour-aligned treads.

Summary of A.T. Informal Trail Conditions

Informal (visitor-created) trails (ITs) result from visitors accessing campsites, water sources, vistas, or other features and their proliferation can be a significant management problem, particularly in areas with rare species or in alpine and sub-alpine zones where plant recovery is slow. Field staff located and mapped 22.8 miles of ITs within a 150-meter (482 ft) wide corridor along each of the 63 5 km sampled segments. If extrapolated to the entire A.T. there are an estimated 255 miles of ITs within the A.T. corridor, with an areal footprint of about 44.4 acres. IT width averaged 16 in, ranging from 14.2 in (VARO) to 21.7 in (NERO) (Table 24). Mean total area of ITs per segment ranged from 1,208 ft^2 (NERO) to 5,460 ft^2 (SORO). Descriptive condition class ratings were applied to ITs, ranging from Class 1 (Slight loss of vegetation cover) to Class 5 (Soil erosion obvious). Based on the sum of Condition Class 4 and 5 percentages, SORO (27.3%) has the most severely impacted ITs, followed by VARO (18%), with NERO having the least impacted ITs (12.3%) (Table 25). The two worst areas of high-density IT development were the Hawk Mountain shelter and campsites (2.8 mi of ITs, 0.41 acres) and the Laurel Fork Gorge (2.1 miles of ITs, 0.45 acres) (Figure 23 and Figure 24).

Summary of A.T. Recreation Site Conditions

Within the 63 sampled A.T. segments field staff found and assessed 504 overnight sites (34 shelters/huts, 405 campsites, 53 side-hill campsites, and 12 side-hill campsites on woods roads) and 227 day-use sites (75 vistas, 122 resting/lunch sites, and 30 combination sites) for a total of 731 recreation sites (Table 28). Extrapolating these findings to the entire A.T. indicates approximately 5,529 overnight sites (including 4,525 campsites and 592 side-hill campsites) and 2,356 day-use recreation sites (Table 28). Forty-nine percent of the sites are within 100 ft of another site (92% for shelter campsites), limiting the potential for solitude and natural quiet. Recreation site distance from the A.T. ranged from 0-1,340 ft with a median of 26 ft (Table 29).

Campsite and shelter sites were about equally split across three campsite expansion potential ratings but 79% of constructed side-hill campsites were rated “poor” (Table 30). Recreation ecology research reveals grasses and sedges, (which are shade-intolerant) to be substantially more resistant and resilient to trampling damage than forest broad-leafed herbs (which are shade tolerant). For all recreation sites, 60% are under tree canopies with greater than 75% cover, 70% for campsites and 21% for shelter sites (Table 30). A quarter (26%) of shelters are located under canopies of <5%; field observations reveal that most shelters were originally located under full canopies, but intensive camping activity and natural processes over many decades has caused substantial tree damage, mortality, and felling without replacement. A positive “advantage” of losing tree canopies over shelter sites and campsites over time is that the additional sunlight penetration is allowing trampling-resistant grasses to slowly replace the original forest herbs.

Resource conditions on recreation sites were rated by descriptive Condition Class along with measurements and estimates of their size, vegetation loss, damaged and felled trees, and several other indicators. While 36% of recreation sites were rated Class 1 or 2, 30% of sites were rated in the more highly impacted Class 4 or 5 (Table 32). Recreation site size ranged from 8-16,190 ft^2 with a median of 400 ft^2 (Table 33). The aggregate area of disturbance for all sites was 15.5 acres, which extrapolates to an estimated 172 acres for all A.T. recreation sites. Overnight recreation sites (504, 69%) account for 80% of the aggregate area of impact for all site types, while day-use sites (227, 31%) account for the remaining 20% of impact (Table 36). While most recreation sites are small (56% are <500 ft^2), 13% are greater than 2000 ft^2, which we define as “mega-sites.” Most mega-sites are campsites (57) or shelter sites (23). Regional data reveal that camping disturbance is more than twice as extensive in SORO (44 ft^2/acre) as compared to VARO and MARO (21 ft^2/acre), with NERO (12 ft^2/acre) having the lowest value (Table 35). The substantially greater camping impact in SORO is attributed to the large annual thru-hiker bubble of use, which acts to substantially expand campsite numbers and sizes during the spring period of exceptionally high use, while subsequent rotating use during the rest of the year prevents meaningful natural recovery.

Seven additional resource condition indicators are presented for recreation sites in Table 33 and Table 36. For example, field staff assessed 1,156 damaged trees on recreation sites, finding 92% on overnight sites and a greater frequency of tree damage on shelter sites than campsites. Tree damage was only assessed within recreation site boundaries; field staff often observed considerably larger numbers of damaged trees in adjacent offsite areas. Similar findings occurred for tree stumps, with field staff recording 1,275 stumps, 76% of which were on overnight sites and a greater frequency on shelter sites.

Regression modeling was conducted to identify the most influential factors affecting campsite size and area of vegetation loss on campsites. Results identified three key factors that managers can use to increase the selection of campsites able to sustain intensive long-term use while resisting the chronic problems of site expansion and proliferation. The most influential factor was the percent of offsite terrain around a campsite with slopes >15%; steep slopes effectively constrict and spatially concentrate camping activity to small campsites without reliance on visitor education or regulation. Campsite type was the second most influential factor, finding that shelter sites are significantly larger than campsites, which in turn are significantly larger than constructed side-hill campsites. This is partly attributed to the substantially greater use that shelter areas receive, but the small sizes of side-hill campsites can be directly attributed to their location in more steeply sloped terrain. Finally, micro-topography is also an important influence in some locations where off-site rugosity, mostly rockiness, was found to also constrict site expansion pressures.

GIS procedures were also applied to the overnight sites to cluster or group all sites closer than 100 ft from each other; this process began with 504 overnight sites and yielded 272 clusters. Two of the clusters had an aggregate campsite size sum of greater than 20,000 ft^2, with extrapolation to the entire A.T. suggesting that there are about 22 such “mega-cluster” campsite locations on the entire A.T. The largest of these clusters was the Hawk Mountain Shelter and associated campsites prior to the management intervention that moved much of the tent camping to 30 side-hill campsites constructed nearby. An examination of the ten largest “mega-clusters” from the sample found that they accounted for 30% of the aggregate areal extent of impact from all overnight sites (Table 42), and for similar percentages of aggregate impact for stumps and damaged trees. Most (7 of 10) include a shelter (high use) and 6 of 10 are in the southernmost three A.T. states (thru-hiker bubble effect). Additional analyses suggested that the source of the large aggregate sizes for mega-clusters can be site expansion, site proliferation, or a combination of both (Figure 28).

A small special study was conducted during the 2016 field season within the southern third of the A.T. to examine the potential impact of expanding hammock camping along the A.T. A 2019 survey of thru-hikers found that 11% of thru- and section-hikers used a hammock as their primary shelter (Mariposa 2020). Field staff examined the most likely pairs of hammock trees on and near all overnight sites in 2016 but found only 13 occurrences of “minor” visible hammock damage. Staff were unable to assess the degree to which hammock camping in offsite areas could be contributing to site expansion.

In NERO overnight and day use recreation site data from the sub-alpine (3,500-4,500 ft) and alpine (>4,500 ft) zones are compared to the non-alpine (<3,600 ft) zone to examine high elevation visitor impacts (Table 43). There were 6 recreation sites, including a large shelter site, in the sub-alpine zone with a sum of 4,717 ft^2 and a median size of 274 ft^2 (compared to 445 ft^2 for low elevation sites) (Table 43). There were 4 day-use recreation sites, including a large vista site, in the alpine zone with a sum of 3,159 ft^2 and a median size of 582 ft^2.

Discussion Summary

Recreation may endanger the goal of resource protection just as protecting resources may restrict opportunities for recreation. These apparently conflicting dual mandates present a management challenge to the A.T. community and underscore the need for effective visitor management and resource protection programs to balance visitation with its associated resource impacts. This research provides baseline data on visitation impacts within the 250,000-acre A.T. corridor. The A.T. management community can review these findings to evaluate the acceptability of the resource impacts that were documented and the need for correction actions. This research also provides statistical relational analyses and modeling that yielded information to assist managers in the selection of effective management actions. Often referred to as Best Management Practices, the practices that science and management experience have revealed as most effective are described in an accompanying report titled “Sustainable Camping “Best Management Practices” and in the Discussion section of this report.

Trail Management Strategies and Actions

While there are some portions of the A.T. that receive heavy traffic most of these have or can be sustainably managed by increasing the design-width of the tread, shifting it to side-hill alignments in sloping terrain, improving water drainage, and hardening the tread by augmenting substrates with rock or angular gravel. Bog bridging or boardwalks are sustainable options for areas with wet soils and paving is an option for areas where the trail passes through towns, accommodates exceptionally heavy traffic, or needs to be accessible to those with disabilities. In areas of heavy traffic visitors sometimes venture off-trail to escape crowds, which pose problems in sensitive settings (e.g., sub-alpine and alpine zones) or when rare flora and fauna are present.

Research findings suggest that the A.T. is not sustainably designed in some areas, though in some of these the trail has likely already eroded to rock. Sustainability assessments could be applied to the entire trail, but accurate GIS-based analyses would require LiDAR data which is not yet available. In general, it’s best to relocate non-sustainable A.T. segments to more sustainable alignments, though enhanced tread construction practices can be applied when relocation is not an option. The most sustainable alignments have grades below about 10%, are not aligned closely to the fall line, and have side-slopes ranging from 30-50% (landform grade).

When sustainable alignments are not possible, trail managers can compensate by substituting enhanced tread construction and maintenance work. This includes greater attention to water drainage, hardening/augmenting tread substrates with rock and angular gravel, and using bog-bridging or boardwalks in wet areas. Steep terrain requires stone steps or staircases and a variety of actions may be necessary to narrow traffic in flat terrain or on fall-aligned segments. Whenever possible, maintainers should employ short grade reversals of the entire tread to improve tread drainage, rather than wood or rock water bars and drainage dips.

Informal Trail Management

Visitor-created informal trails are often less sustainable than formal trails and may receive little to no maintenance. They are therefore more susceptible to degradation and may pose a threat to water quality or sensitive flora and fauna. Most ITs are necessary to access vistas, campsites, or water, though duplicative trails and high densities of ITs in popular areas do represent “avoidable” impact that pose resource protection threats in some areas. Some ITs could be formalized and managed to reduce resource impacts while others could be closed and restored.

Recreation Site Management Strategies and Actions

Trampling-related visitor impacts to vegetation and soils have an asymptotic relationship with amount of use such that most impacts occur with low to intermediate traffic. For example, above about 15 nights of camping a year, campsites deteriorate very little with each additional night of use. However, the number of campsites needed is related to the total amount of use that must be accommodated in a given place and time. The substantial growth in the annual A.T. thru-hiker “bubble” of use has created significant numbers of campsites in the southern states, and site expansion and proliferation are creating an increasing number of mega-sites and mega-clusters of sites. The A.T. community has developed practices for addressing these problems, most notably in the White Mountains by designating campsites and at Annapolis Rocks (MD) and Hawk Mountain (GA) by shifting use from flat terrain to constructed side-hill campsites. This research demonstrates that there are many additional mega-cluster campsite complexes that likely require similar management attention.

The long-time management traditions of focusing traffic on sustainably designed and maintained trails is also suggested for managing overnight camping. While shelters have been constructed and are effective in spatially-concentrating camping activities to a small “footprint” of impact, the same is not true for campsites. Many visitors have chosen to establish campsites in large flat areas near water which are highly vulnerable to future site expansion and proliferation. Visitors also often create large numbers of unnecessary campsites with low occupancy rates that represent avoidable impact. Research data reveal that the largest site numbers and areal extent of camping impact occur in the southern states and we attribute this to the large and growing thru-hiker bubble of use. Preliminary data reveal that the bubble includes many section-hikers and short-duration campers who could possibly be shifted in time and space to reduce camping demand, along with existing efforts to encourage a wider dispersion of start dates, flip-flop thru-hiking models, and efforts to minimize popular events like the Damascus Trail Days Festival that can reconstitute mid-hike bubbles of high use. A greater focus on these visitor redistribution efforts is warranted and the Visitor Use Management framework provides a professional tool for accomplishing such work.

Research findings provide additional guidance for the selection or construction and maintenance of more sustainable campsites and suggest the need for implementing a containment strategy with either established or designate site camping in areas of moderate to high camping activity. Under established site camping professionals select or create sustainable campsites and encourage visitors to use them. These sites could be marked with paint blazes and included on phone apps to aid visitors in finding and using them. In the most popular areas visitors may be required to use only sustainably selected or constructed designated campsites, marked and included on maps, guidebooks, and phone apps.

Relational analyses found that the most sustainable campsites occur on naturally-occurring or constructed side-hill campsites, where surrounding steep terrain acts to constrain site expansion and proliferation and spatially concentrate camping activities to the intended areas. Rugosity (rockiness) in offsite areas and open forests with sufficient sunlight to support grasses were also influential factors in minimizing site sizes and aggregate impact. Ongoing research is exploring and perfecting GIS and ground-based capabilities for identifying the most sustainable existing campsites and locations for creating new sustainable sites. When camping must be accommodated in flat terrain managers can construct improved visually-obvious tent pads with wood or rock borders to attract and constrain camping activities. A program of closure and restoration work can also be beneficial. The sustainable camping BMP report describes a comprehensive array of camping management strategies and practices for use by A.T. maintainers.

A continued emphasis and expansion of Leave No Trace educational messaging and courses is also supported, as the A.T. has many repeat visitors and wide-spread adoption of low impact practices would significantly reduce visitor impacts. More experienced hikers who are solo or in small groups could effectively eliminate camping impacts by practicing pristine site camping, or by adopting hammocks.

Finally, improved trail and campsite condition monitoring programs could benefit VUM decision-making, providing an essential tool for periodically assessing resource conditions for comparison to indicator thresholds (standards) and for evaluating the efficacy of implemented management actions. The protocols developed for this research and included in Appendix 2 can be adapted to provide reliable methods for monitoring trail and recreation site conditions.

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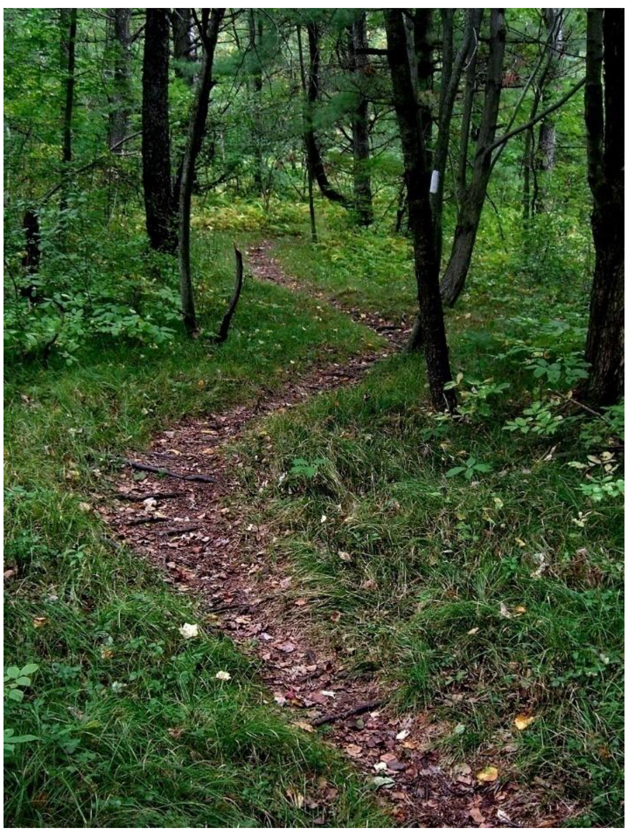
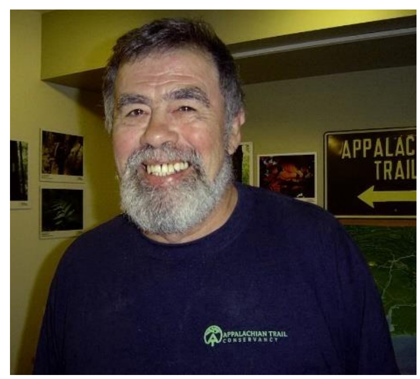
Dedication

This research report is dedicated to Bob Proudman … colleague, friend, and mentor.





INTRODUCTION

The National Park Service Act (1916) provides a mandate to the National Park Service "*to promote and regulate the use of the Federal areas known as national parks, monuments, and reservations…by such means and measures as conform to the fundamental purpose to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations."* This guidance provides park managers with a "dual mandate," directing them to: 1) make parks available for public visitation and enjoyment, and 2) preserve the natural and cultural resources within parks. This challenge becomes increasingly difficult as more people visit parks.

The NPS manages 418 park units and more than 84 million acres of protected lands, accommodating over 300 million visitors annually. Included within these units are National Scenic Trails (NST's), including the 2,200-mile Appalachian National Scenic Trail (A.T.), which is collaboratively managed with the Appalachian Trail Conservancy (ATC), other federal, state, and local land managers, and a large volunteer community of A.T. trail clubs. The National Trails System Act of 1968, celebrating its 50th anniversary in 2018, established the A.T. and the Pacific Crest Trail as the first two of eleven current NST's, managed to "provide for maximum outdoor recreation potential and for the conservation and enjoyment of the nationally significant scenic, historic, natural, or cultural qualities of the areas through which such trails may pass" (National Trails System Act, P.L. 90-553, as amended by P.L. 111-11).

An increasing number of protected area visitors inevitably contribute negative effects to fragile natural and cultural resources. Such visitation-related resource impacts can degrade natural conditions and processes and the quality of recreation experiences. According to the NPS *Management Policies*: The fundamental purpose of the national park system, established by the Organic Act and reaffirmed by the General Authorities Act, as amended, is to conserve park resources and values (NPS 2006, Section 1.4.3). The NPS *Management Policies* acknowledge that some resource degradation is an inevitable consequence of visitation but directs managers to "ensure that any adverse impacts are the minimum necessary, unavoidable, cannot be further mitigated, and do not constitute impairment or derogation of park resources and values" (NPS 2006).

Responding to these concerns, the ATC and NPS managers at Appalachian Trail Park Office (ATPO) requested and the NPS funded this research investigating the resource impacts associated with more than three million A.T. visitors annually. The information provided by this research is vital for science-based planning and decision-making to accommodate recreational visitation while protecting unimpaired the vast natural resources of the longest U.S. National Park. More specifically, park staff and the A.T. community require information from this study to improve the overall sustainability of the trail's recreation infrastructure and address topics that include carrying capacity and the quality of visitor's experiences. This research will enhance managers abilities to protect the A.T.'s natural resources by investigating factors that influence the nature and severity of visitor impacts and the sustainability of the trail and its overnight and day-use recreation sites. Principal products include a quantitative characterization and documentation of baseline conditions, relational analyses and evaluations of factors that influence trail and recreation site sustainability, and Best Management Practices, including improved capabilities for assessing, selecting, and managing sustainable trail alignments and recreation sites.

This research is necessary due to the high and increasing A.T. visitation, but also to provide essential information as the A.T. community begins implementation of the new Visitor Use Management (VUM) framework, especially regarding carrying capacity decision-making, and in the future when it revises its Comprehensive Plan. It will also aid managers in responding to an increasing number of special uses, including group use, commercial use, special events, and other uses that require information to adequately address resource protection decisions. Finally, the research will address climate change impacts associated with extreme weather and precipitation events. For example, in 2011, an extreme precipitation event washed out miles of unsustainably designed A.T. tread in Vermont, which were unable to shed run-off quickly enough to avoid substantial soil erosion. In contrast, sustainably designed trail alignments were left intact. Finally, visitor impacts to rare flora and fauna, including sensitive high-elevation plant communities most susceptible to climate change, will also be a focus of the investigation to enhance their protection.

Finally, this research is advancing basic knowledge in the recreation ecology field of study that will benefit protected areas worldwide. The A.T. dataset is the largest and most comprehensive recreation ecology dataset ever collected in the U.S. or internationally. It includes research-level measures of a diverse array of trail and recreation site indicators and dozens of potentially influential factors. We reviewed and refined indicator protocols from prior studies, added new indicators and protocols, and added new indicators through extensive Geographic Information System (GIS) analyses, including many derived from newly available LiDAR topography datasets. Specifically, it includes representative A.T. data from 3,150 spatially-sampled trail transects and from 227 day-use recreation sites and 504 overnight shelters and campsites. The dataset is derived from a diverse array of environmental conditions, latitudes, elevational gradients, geologic, soil, and plant community types, as affected by a variety of recreational hiking and camping activities. These data are supporting numerous multivariate relational analyses that model the role and influence of factors affecting an array of trampling and camping impacts, knowledge that will enhance corrective management actions.

In comparison to other NPS units, the Appalachian Trail has received scant research attention, yet it encompasses five NPS Inventory and Monitoring networks and preserves nationally significant scenic, historic, natural, and cultural resources. The A.T. accommodates heavy and spatially intensive visitation with potentially significant but largely unknown and undocumented impacts.

Project Objectives

This research focuses primarily on resource protection concerns, particularly those related to trampling and camping impacts, but social (experiential) impacts are also considered. Study objectives include:

1. Provide quantitative, representative, spatially-related baseline documentation of the A.T. tread, informal trails, and recreation sites (overnight and day-use) to characterize the type, areal extent, and severity of visitation-related resource impacts to vegetation and soils,

2. Statistically analyze data to evaluate trail design and alignment attributes and recreation site biophysical attributes to develop sustainability models, ratings, and guidance,

3. Conduct multivariate analyses of tread and site data to identify and describe the relative influence of key use-related, environmental, and managerial factors that can be manipulated through design and management actions to minimize resource and experiential impacts,

4. Assess visitor impacts to sensitive vegetation communities and species and the sustainability of the A.T. tread to climate change, particularly to climate change related extreme weather events,

5. Conduct spatial statistical analyses to evaluate how trail and site conditions and design attributes vary across latitude, elevation, ecoregions, plant and soil types, and management jurisdictions,

6. Formulate Best Management Practices describing actions (educational/interpretive, regulatory, and site/facility management) that avoid or minimize resource and experiential impacts,

7. Apply sustainable trail and recreational facility construction and design principles through workshops with ATC field staff and volunteer trail maintainers, and

8. Develop and communicate refined Leave No Trace practices and outdoor ethics through guidance for pamphlets, signs, online/digital media, and teaching curricula. Assist with outreach activities to deliver these products using oral and written communication, websites, and social media.

LITERATURE REVIEW

This section begins with a review of the resource impacts associated with visitor use, which can degrade existing trails and recreation sites or lead to the expansion or creation of new informal trails and recreation sites. Next, we include a review of federal agency management guidance related to visitor use, followed by a review of the literature on agency management frameworks that may be applied to assist managers in evaluating and managing the impacts of visitation, highlighting the new Interagency Visitor Use Management Council (IVUMC) framework (IVUMC 2016). We also include a review of the literature on methods for monitoring visitor use impacts to trails and recreation sites, and some guidance for selecting preferable indicators to monitor relative to management thresholds (standards).

Visitation-Related Resource Impacts

Visitors participating in various types of recreational activities, including day-hiking, camping, and backpacking, contribute to a diverse array of direct and indirect impacts on protected area resources, including vegetation, soils, water, and wildlife (Table 1). The term *impact* is commonly used to denote any undesirable visitor-related change in these resources. Marion et al. (2016) provide a comprehensive review of these trampling-related impacts, which are summarized here. Even light recreational traffic can reduce ground vegetation height, cover, and biomass (Cole 1995a,b, Cole 2004, Leung & Marion 1996). Trampling disturbance can alter the appearance and composition of vegetation by reducing plant height and favoring trampling resistant species. Plant resistance is the intrinsic capacity of vegetation to withstand the direct effect of trampling by feet, hooves, and tires (Liddle 1997).

Under light recreational traffic, most plants respond with a reduction in plant height. Even light trampling will break rigid stems, which can halt flower and seed development and reduce plant vigor (Barros & Pickering 2015, Cole 1987). Plant morphological characteristics influence the response of vegetation to trampling disturbance. The taller rigid stems of many forest forbs (herbs) are highly susceptible to trampling damage, with stem breakage eliminating the growing tips, flowers, and seed production (Cole & Monz 2002). In contrast, grasses and sedges have flexible stems and leaves that are considerably more resistant to traffic and research has shown them to be significantly more resilient, i.e., they recover relatively quickly. Studies reveal that these differences in morphology and trampling resistance/resilience are positively correlated with the amount of sunlight that reaches ground vegetation (Cole & Monz 2003, Liddle 1997), i.e., shade-tolerant forest plants lack the resistance and resilience of shade-intolerant (sun-loving) plants.



Table 1. Direct and indirect effects of recreational trampling on soils and vegetation.

Effects	Vegetation	Soil
Direct	Reduced height/vigor	Loss of organic litter
	Loss of ground vegetation, shrubs and trees	Soil exposure and compaction
	Introduction of non-native vegetation	Soil erosion
Indirect	Altered composition – shift to trampling resistant or non-native species	Reduced soil pore space and moisture, increased soil temperature
	Altered microclimate	Increased water runoff
		Reduced soil fauna

Higher levels of trampling cause more complete ground vegetation loss and compositional change (Cole 1995b; Marion & Cole 1996). Concentrated traffic also pulverizes soil leaf litter and humus layers, which are either lost through erosional processes or intermixed with underlying mineral soils (Marion et al. 2016). These soils then become exposed and vulnerable to displacement, wind or water erosion, and compaction (Monti & Mackintosh 1979). The compaction of soils decreases soil pore space and water infiltration, which in turn increases water runoff, muddiness, and soil erosion (Liddle 1997).

Severe trampling impacts, such as erosion and muddiness, often cause additional avoidable impact to water resources or to vegetation and soils in the form of recreation site expansion or trail widening and formation of parallel secondary trails. Recreation site expansion and trail widening can substantially expand the cumulative spatial extent of disturbance (Leung & Marion 1996, Marion et al. 1993). Trails and recreation sites can also alter natural patterns of water runoff (Sutherland et al. 2001), resulting in irreversible soil erosion and subsequent turbidity and deposition in streams and other water bodies (Fritz 1993, Leung & Marion 2000). Finally, research demonstrates that the quality of a visitor's experience is likely to decrease when substantial resource degradation is present (Lynn & Brown 2003).

Recreational activities can also directly degrade and fragment wildlife habitats, and the presence of visitors may disrupt essential wildlife activities such as feeding, reproduction and the raising of young (Knight & Cole 1995, Marion et al. 2016). For example, Miller and others (1998) found decreased presence of nesting birds near trails in grassland ecosystems. Trails can fragment the landscape with barriers to flora and some small fauna (Leung *et al.* 2002, 2011, Leung & Louie 2008). Finally, visitors and recreational stock can also introduce and transport non-native plant species along trails and between recreation sites, some of which may out-compete undisturbed native vegetation and migrate into adjacent undisturbed areas (Adkison & Jackson 1996, Benninger-Truax *et al.* 1992, Bhuju & Ohsawa 1998, Eagleston & Marion 2018, Hill & Pickering 2006, Potito & Beatty 2005).

Formal Trail Impacts

Trail Soil Loss

Soil loss as measured in trail studies is largely caused by water erosion, though wind can remove tread soils in dry climates, and soil can be compacted or displaced downhill or laterally (Marion & Wimpey 2017). The rate and severity of soil loss is influenced by trail alignment relative to topography and environmental attributes, tread substrates, climate, tread maintenance actions, and use-related factors including amounts and types of use (Leung & Marion 1996, Olive & Marion 2009).

Many trail studies have revealed a strong positive relationship between soil erosion and high trail gradients, with soil loss increasing substantially with grade (Bratton et al. 1979, Dissmeyer & Foster 1980, Fox & Bryan 2000, Marion & Wimpey 2017, Nepal 2003, Olive & Marion 2009). This trend is explained by the increased erosive force of water and increased soil displacement by boots, wheels, and hooves on steeper trail treads (Fox & Bryan 2000, Leung & Marion 1996).

Two metrics have been developed to describe a trail route's alignment to landform topography. Trail practitioners use Slope Ratio (SR), which is calculated by dividing the landform grade by the trail grade and ranges from 0.0 to 1.0 (IMBA 2004). Fall line trails are nearly as steep as their surrounding terrain and have high SR values close to 1, whereas side-hill trails have low SR values closer to 0. Some trail researchers use Trail Slope Alignment (TSA), a measure of the smallest angle between the azimuth of the trail and the azimuth of the prevailing fall line, expressed in angular degrees ranging from 0° to 90° (Marion & Wimpey 2017)

Direct ascent trails with TSA values lower than 22° are particularly prone to soil loss due to the difficulty of draining water from incised treads – both side-slopes are often higher than the tread surface (Marion & Wimpey 2017). For example, predictive equations from a study in Big South Fork National River and Recreation Area in Kentucky and Tennessee suggest that every degree that TSA alignments shift from 90° (side-hill) to 0° (fall-line) contributes $6cm^2$ of additional soil loss (Olive & Marion 2009). Several studies report that the significance of TSA increases as trail grade increases (Bratton et al. 1979, Leung & Marion 1996, Marion & Wimpey 2017, Olive & Marion 2009).

Soil texture, reflecting the relative amounts of different substrate particle sizes, influences the ability of soils to withstand wind and water erosion, displacement, and compaction. When dry, uniformly fine-grained soils are highly compactible and resistant to erosion; coarse-textured soils drain easily but are displaced with little force (Hammitt et al. 2015). An ideal tread substrate has a mixture of grain sizes, including sand to improve drainage, fine silts for cohesion, and rock or gravel to harden the tread and deter soil displacement (Leung & Marion 1996, Marion et al. 2016).

Since rainfall and snowmelt mobilize and displace soil, the amount and intensity of precipitation influences the severity of soil loss (Bratton et al. 1979, Leung & Marion 1996, Tomczyk et al. 2016). High elevation trails with limited rock in tread substrates can be more vulnerable to erosion due to the combined effects of high precipitation, strong winds, and numerous freeze-thaw cycles (Nepal 2003). Trailside vegetation can limit erosion by protecting exposed soil from splash, slowing and filtering runoff, and increasing soil porosity with roots (Bratton et al. 1979). More rarely, soil loss can be prevented by the growth of trampling-resistant grasses, sedges, or short herbs, generally only on low use treads in sunny settings (Dixon et al. 2004, Marion et al. 2016).

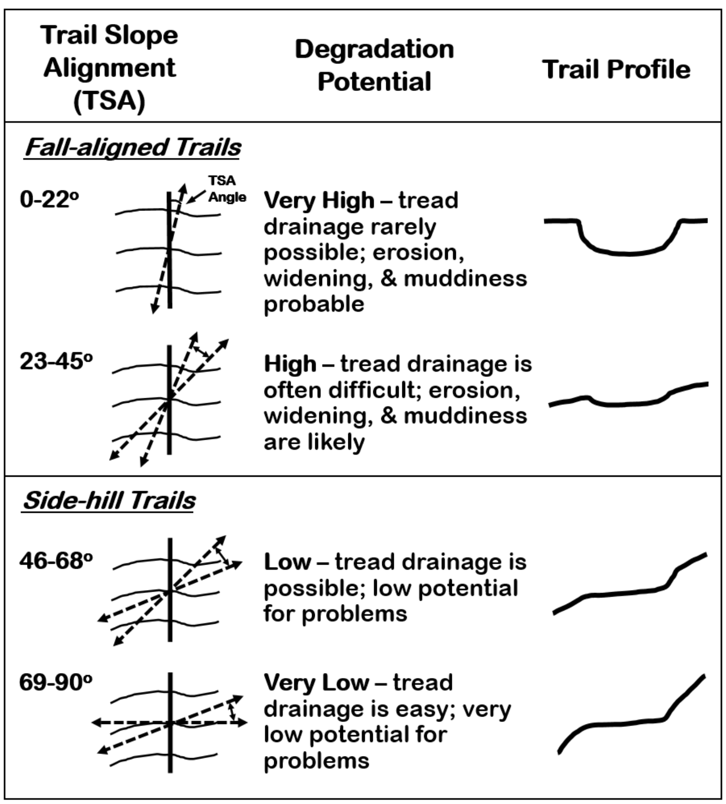


Figure 1. Trail Slope Alignment (TSA). Expected trail degradation potential and trail cross-section profiles for four categories of trail slope alignments ranging from fall-line trails (0-22°) to contour-aligned side-hill trails (69-90°). Dashed lines depict trail alignment and solid vertical lines depict the prevailing landform grade or aspect.

One objective of sustainable trail design is for trails to be "hydrologically invisible;" to not intercept and divert water along their treads. However, trails constructed with out-sloped treads to shed water rarely retain out-sloping when opened. This is due to soil compaction and displacement from initial trail traffic, and over time to tread substrate erosion and the development of a raised berm along the lower trail border (Parker 2004). In the absence of effective maintenance, trails will intercept and divert erosive water along their treads. Trails require a permanent program of tread drainage and maintenance to avoid or minimize soil loss, with amount and frequency of maintenance inversely correlated with the sustainability of a trail's alignment. Removing water from fall-line trails is difficult or impossible when treads become deeply incised (IMBA 2004, Parker 2004). Trailside berms on side-hill trails can be excavated to promote drainage but this is a strenuous task over long distances (Hesselbarth et al. 1996, Marion & Wimpey 2017). More commonly maintainers install rock or wooden water bars and drainage dips to minimize erosion by diverting flowing water from treads (Birchard & Proudman 2000, Hesselbarth et al. 1996). Research reveals greater soil loss with increasing distance from drainage features, that feature density must increase with increasing trail grade, and that drainage features become ineffective when not maintained (Marion & Wimpey 2017, Mende & Newsome 2006). Water bars are difficult to properly design and construct, become ineffective when filled with sediment, and are often circumvented by hikers, widening the trail (Hesselbarth et al. 2007). The most sustainable option for diverting water from treads is to periodically reverse the grade of the trail, forcing all water off the trail and lessening the need for maintenance (Marion & Wimpey 2017, Parker 2004). Tread grade reversals are optimally designed during a trail's layout, though rolling grade dips can be retrofitted on side-hill trails with low to intermediate grades (Hesselbarth et al. 2007, IMBA 2004, 2007).

Maintainers can also avoid or minimize soil loss by armoring treads with rock or wood. The addition of stonework, imported gravel or crushed native stone may seem unnatural but can be an effective practice to create highly resistant treads, particularly when both fine and coarse particles are combined (Marion 2016a). Mixing gravel with native soil in an effective practice to create highly resistant substrates that remain natural in appearance. Coarse gravel applied to steep trail grades is not a sustainable practice as the gravel will displace or erode down-slope, requiring labor intensive re-application and maintenance (Marion & Wimpey 2017, Olive & Marion 2009). Steeper trail grades generally require the construction of well-anchored rock steps or armoring to prevent erosion but no available research has examined their long-term efficacy (Marion 2016a). A variety of geosynthetics are also available, including geotextiles, sheet drains, and geo-cells, and while most are installed in flat terrain to address muddiness, some have been applied to prevent erosion (Hesselbarth et al. 2007, Marion 2016a). Research on the efficacy of geosynthetics is also rare, and the high cost and artificial nature of these materials discourage their use, particularly in backcountry and wilderness settings (Marion & Leung 2004).

Types and amounts of trail use have also been shown to influence soil loss, though most studies report their effects are less influential than trail alignment and substrate factors (Cole 1991, Marion & Wimpey 2017). Most tread impacts occur with low to moderate use, with diminishing per-capita impact occurring at higher use levels, particularly on well-maintained sustainably designed trails. However, intensive use during wet periods can accelerate tread soil displacement and loss (Farrell & Marion 2001, Nepal 2003). Several studies have also observed significantly more soil displacement and loss on equestrian trails relative to hiking and mountain biking trails (Bratton et al. 1979, Leung & Marion 1999, Olive & Marion 2009).

Trail Muddiness

While studies suggest that soil loss is primarily caused by moving water, trail muddiness is caused by poor drainage and water retention. Although a common problem in many trail systems during wet seasons (Cole 1983, Leung & Marion 1999, Nepal 2003), little research has been focused on modeling the factors that influence trail muddiness. Trails routed through flat areas are prone to muddiness because it is difficult or impossible to drain water from their incised treads (Cole 1983, Tomczyk et al. 2017). Trails in areas with high water tables or on soil types with substantial organic content that retain water often become muddy quagmires (Bratton et al. 1979, Cole 1991, Leung & Marion 1999).

Mud-holes form most often in flatter valley bottoms in areas of poor drainage or near seeps and springs (Bratton et al. 1979, Leung & Marion 1999, Nepal 2003). Water retention and muddiness can also occur on incised sections of nearly level side-hill trails and ridge-tops when insufficient maintenance allows berms to form and/or drainage features to clog (Bratton et al. 1979, Hesselbarth et al. 2007, Leung & Marion 1999). The most sustainable solution is to relocate persistently muddy trail segments to side-hill alignments with sloping trail grades (e.g., >5%) (Hesselbarth et al. 2007, Steinholtz & Vachowski 2001). When relocations are not possible, trail maintainers can harden muddy sections with rock, puncheon, geosynthetics, or elevated bog bridging (Birchard & Proudman 2000, Hesselbarth et al. 2007). For side-hill trails the enhancement and maintenance of drainage is an effective solution to muddiness.

Trail Widening

Unlike soil loss and muddiness, which are primarily driven by water, trail widening is rooted in visitor behaviors, most frequently related to visitors selecting the smoothest and easiest route of travel (Cole 1991, Wimpey & Marion 2010). Unmitigated degradation on poorly routed trails can prompt visitor behaviors that contribute to trail widening; hikers meandering laterally over eroded rocky and root-covered treads in search of the best footing often pioneer smoother areas adjacent to the degraded treads (Leung & Marion 1999, Tomczyk et al. 2016, Wimpey & Marion 2010). Similarly, trail users frequently sidestep wet and muddy trail sections, creating multiple treads and wide mud-holes (Bayfield 1973, Leung & Marion 1999, Tomczyk et al. 2017). Additional trail widening behaviors identified by Wimpey and Marion (2010) include visitors moving laterally to pass or allow passing, and side-by-side travel; trail widening associated with these behaviors is generally related to variations in visitor travel patterns and numbers.

Some motorized vehicles and equestrians have a functional need for wider trails but these trail uses can also have greater speeds, travel distances, ground pressures, and soil displacement from churning hooves and tires that collectively contribute to greater trail widening (Marion & Olive 2006, Svajda et al., 2016, Tomczyk et al. 2017).

Despite the strong behavioral linkages associated with trail widening, research reveals that trail routing relative to topography and trail maintenance actions can significantly influence trail width. Trails in flat terrain are prone to widening due to the ease of off-trail travel, while the steeper side-slopes of side-hill trails effectively center and concentrate traffic to inhibit tread widening (Bayfield 1973, Wimpey & Marion 2010). Maintainers can manipulate the density of trailside vegetation and the width of the trail corridor through trimming and forest management practices (Bayfield 1973, Bright 1986, Hesselbarth et al. 1996, Tomczyk et al. 2017). In non-forested areas, the substantial trampling resistance and resilience of grasses and sedges can effectively resist trail widening pressures, though sloping terrain is required to prevent the formation of parallel secondary treads and muddiness (Tomczyk & Ewertowski 2011, Tomczyk et al. 2017).

Both natural and intentionally placed trailside rocks, logs, and woody debris can effectively center traffic (Bayfield, 1973). Constructed trailside barriers including stone or wooden borders, scree walls, and fencing, can physically obstruct traffic or serve as visual cues to center and concentrate traffic (Park et al. 2008, Svajda et al. 2016, Tomczyk et al. 2017, Wimpey & Marion 2010). Finally, preventing or mitigating degraded trail conditions, particularly muddiness and rugosity (exposed roots or rocks caused by erosion), can motivate visitors to remain on the intended tread.

Recreation Site and Informal Trail Impacts

Recreation sites include day use sites (e.g., vistas and resting spots) and overnight use sites (e.g., campsites and shelters) that receive concentrated visitor use (Leung & Marion 2004). Many recreation sites, even sites designated by land managers, were originally selected and created by visitors. As with trails, many recreation sites are poorly located with respect to resource protection considerations and are thus susceptible to environmental impacts from trampling. Most site impacts are caused by trampling and are similar to those previously described for trails (see Table 1). Differences include the nodal configuration of trampling disturbance, tree damage, and campfire related impacts.

Recreation site expansion proliferation, the persistent creation of new sites by visitors, are generally the most significant resource impacts of concern to land managers, whose primary objective is to limit the aggregate areal extent of visitor impact (Marion et al 2018a). For example, when camping is unconfined (unregulated), surveys reveal that visitors frequently create substantial numbers of unnecessary sites, often in popular high-use locations where sites expand in number and size and merge, forming dense mega-clusters with substantially degraded ecological and social/experiential conditions (Cole 2013, Daniels & Marion 2006, Marion et al. 2018a).

Recreation sites can range in size from several hundred to more than 8,000 ft^2 (Marion & Cole 1996), generally more than half of which is non-vegetated and more than one-quarter has also lost most organic litter. These larger expanses of exposed soil are generally in flatter terrain, though sheet erosion can remove large amounts of soil over time. Soil erosion is a more substantial problem when recreation sites are located along shorelines, where eroded soil from the site and steeper shoreline access trails can drain runoff directly into waterways (Marion et al. 2018b). Other concerns related to their large size are the loss of woody vegetation and its regeneration over time. Gaps in forest canopies caused by trampling and tree cutting can alter microclimates and create sunny disturbed locations that promote invasive vegetation.

The scientific literature and management experience reveal an extensive list of resource impacts attributed to campfires. Campfires are an especially challenging issue for public land managers because fires remain an important aspect of many visitors' camping experience, despite the increased use of backpacking stoves (Christensen & Cole 2000). Campfires result in aesthetic and ecological impacts to protected natural areas. Although the most obvious impacts tend to be focused on specific areas within recreation site boundaries, wood collection and wildfire impacts resulting from campfires are more broadly distributed and affect larger areas.

Campfires alter soil properties. Fenn and others (1976) measured the effects of campfires on soil regimes and concluded that intense campfires can reduce organic matter content to a depth of more than four inches. The researchers also found that campfires result in substantial alterations of soil chemistry. The reductions in organic matter and subsequent chemical changes diminish soil fertility and water holding capacity, making the soil prone to erosion and compaction (Fenn & others 1976). Fire sites also attract litter and garbage when visitors attempt to dispose of wastes through burning (Reid & Marion 2005). The combustion of plastic, paper and metal garbage can contribute chemical contaminants to fire site ashes. Davies (2004) analyzed gas emissions and ash content from 27 products commonly burned in campfires and found greatly increased levels of a variety of toxic materials, including some that pose a threat to human health. Partially burned food items retain odors, thereby promoting attraction behavior among area wildlife.

Firewood collection also degrades natural resources over a larger area for impacts such as vegetation trampling and tree damage, including the felling of trees. Tree damage, including broken or cut limbs, hatchet wounds and girdling, is an aesthetic impact associated with campfires, but such wounds make trees more susceptible to insect and fungal attacks that can lead to tree mortality (Cole & Dalle-Molle 1982, Reid & Marion 2005). Felled trees due to wood gathering efforts may reduce habitat for cavity-nesting birds while also affecting aesthetic qualities of an area (Cole & Dalle-Molle 1982). Hall and Farrell (2001) assessed the extent of woody material depletion in the Cascade Mountains of Oregon and found a significant reduction in woody materials adjacent to recreation sites when compared to controls. Bratton and others (1982) investigated the effects of trampling and firewood gathering in Great Smoky Mountains National Park and concluded that the collection of downed wood likely affects nutrient cycling over a 50-70 year time frame, but has negligible effects in the short term.

When formal trail networks fail to provide visitors the access and experiences they desire, visitors frequently "vote with their feet" by venturing off-trail to reach locations not accessible by formal trails. Even relatively low levels of recreational traffic can wear down vegetation and organic litter to create long-lasting *informal* (visitor-created) trails (ITs) and recreation sites (Thurston & Reader 2001, Wimpey & Marion 2011). The establishment of ITs and recreation sites is commonplace in protected natural areas, especially in heavily visited areas. The creation and proliferation of ITs and sites can directly impact sensitive plant communities, rare or endangered flora and fauna, and wildlife habitats (Leung et al. 2002, Wimpey & Marion 2011). For example, a small population of rare plants may be eliminated by trampling or habitat changes from visitor use or through competition from introduced non-native species. Off-trail and off-site traffic may also contribute to the further introduction and spread of non-native and invasive plant species.

Resource degradation on ITs and recreation sites is often severe due to their lack of professional design, siting/layout, construction, and maintenance. Such unplanned recreation infrastructure generally receives no environmental reviews, yet they sometimes accommodate considerable use. Furthermore, some park managers have formalized trails and recreation sites that were originally created by visitors (Marion & Leung 2004). Resource impacts to these informal facilities are often linked to their unsustainable alignments and proximity to fragile vegetation, soils, and sensitive wildlife habitats, or their disturbance to rare flora, fauna, or archaeological sites (Wimpey & Marion 2011). These attributes make them substantially more susceptible to resource impact.

In summary, most recreation resource impacts are limited to the immediate vicinity of formal trails and recreation sites, though impacts like the creation of ITs and recreation sites, altered surface water flow, invasive plants, and wildlife disturbance, can extend considerably further into natural landscapes (Kasworm & Monley 1990, Tyser & Worley 1992). However, even localized disturbance can harm rare or endangered species or damage sensitive plant communities, particularly in environments with slow recovery rates.

Visitation-Related Experiential Impacts

As with environmental impacts, managers are also mandated to provide and protect high quality visitor experiences. Visitors may experience either crowding or conflict and managers need to understand the potential for each, how visitors cope, and what this means for recreation and visitor management decision-making.

Social scientists study crowding in natural areas as it relates to the social interface and stimulus overload theories (Manning 2011, Schmidt & Keating 1979). The social interface theory says that visitors feel crowded when the number of people in an area interferes with their goals and objectives. Stimulus overload theory says someone experiences crowding when the presence of others overwhelms them (Manning 2011). Several psychological studies indicate that the feeling of being crowded relies on the setting and the activities taking place. As concluded by Robert Manning in his book "Studies in Outdoor Recreation" (2010), a variety of factors influence a visitor's perception of what is normal, and thus influence if they feel crowded. Crowding is a normative concept: "The normative approach to crowding suggest that use level is not interpreted negatively as crowding until it is perceived to interfere with or disrupt one's objectives or values." Through a synthesis of social science literature centered on outdoor recreation, he groups these differences or factors into three categories: 1) personal characteristics of visitors, 2) characteristics of others encountered, and 3) situational variables.

The **personal characteristics** that affect visitor's perceptions of crowding are motivations for outdoor recreation, preferences and expectations for contacts, experience level, and attitudes toward management:

- If one is *motivated* to get outside for the opportunity for solitude or quietude there is a higher likelihood of experiencing crowding.
- If one *prefers* to have interactions with other people in nature (share the experience) there is a higher threshold of people encountered without feeling crowded.
- If one *expects* to see a lot of people (you know this is a popular spot) there is less likelihood of feeling crowded.
- As you gain more *experience* in an activity or area you may refine your preferences for level of crowding.
- The extent to which *attitudes* conform to how a place is managed (i.e., in accordance with the Wilderness Act) may affect someone's definition of crowding (Manning, 2011).

Factors that affect crowding in relation to **characteristics of other users** can be categorized as one of three types: group type and size, behavior, and degree to which other groups are perceived to be alike (Manning 2011).

Several studies support the view that the type and size of groups that are encountered affects tolerance for meeting another group. Most often groups are characterized by type of activity (Manning 2011). Some of the conclusions drawn from a variety of studies are:

- Users have the highest tolerance for meeting other groups of the same type of activity (Manning 2011, McCay & Moeller 1976).

- Party size may affect the crowding norms; in a wilderness area it was found that people preferred to encounter many smaller groups rather than one large group (Stankey 1973).

A few studies have shown that behavior also affects crowding norms. West (1982) found that 31% of hikers to a Michigan National Forest were disturbed by other users and 57% of those were most disturbed by the *behavior* of other users, particularly: noise, yelling, littering, polluting lakes, and noncompliance with rules (Manning 2011).

Lastly, there are some **situational variables** that can affect perceptions of feeling crowded. These include: the type of area and the location within an area.

- Type of area refers to backcountry (remote areas with mostly overnight visitation) versus frontcountry (accessible areas with mostly day use visitation). For example, a backcountry hiker may feel crowded with relatively few interactions with others but not feel crowded with even more interactions in a frontcountry setting at a popular vista.
- The location within an area refers to intrasite interactions. A visitor may have a higher tolerance of seeing others on a trail or at a shelter, in comparison to seeing them in an off-trail area.

Coping

There are three ways visitors deal with crowding: displacement, rationalization, and product shift. First suggested by Clark, Hendee, and Campbell (1971) as "invasion and succession", displacement theory is the idea that "as use levels increase, some recreationists become dissatisfied and alter their patterns of recreation activity to avoid crowding, perhaps ultimately moving on to less used areas, and are displaced by users more tolerant of higher use levels" (Manning 2011). There can be intersite, intrasite, or temporal displacement. Users will either shift use to another recreation area, shift use within the recreation area (to possibly a less-used trail), or shift the time in which they decide to recreate to a less busy period.

Several studies have found spatial or temporal displacement to have occurred and provide useful insights. Hammitt and Patterson (1991) asked campers in Great Smoky Mountains National Park how often they employed either intrasite or temporal displacement. Between 14-44 percent of those asked reported using these behaviors "usually" or "always" and those who value solitude reported more displacement behaviors. Another study found that visitors who were least sensitive to crowding altered their visit temporally, visitors with moderate sensitivity to crowding altered their route, and those most sensitive terminated their visit (Fleishman et al. 2007).

Rationalization and product shift coping mechanisms involve changes in the way visitors think. Rationalization involves visitors 'rationalizing' their experience and reporting high levels of satisfaction despite the conditions. How much investment (time, money and effort) into planning the experience seems to play a role in when visitors experience this (Manning 2011), with higher investment making it more likely to occur. Product shift occurs when visitors who experience a higher level of use than expected or preferred will alter their view of that area to one that fits with what was experienced.

The Use Impact Relationship

Research indicates that visitor activities occurring on native vegetation can cause fairly rapid impacts. Most forest plant communities have herbaceous ground vegetation that is neither resistant nor resilient to trampling. Even open meadow vegetation with resistant grasses and sedges cannot sustain substantial or intensive levels of persistent or long-term traffic (Marion 2016a, Marion et al. 2016). A large body of recreation ecology research reveals that the relationship between amount of visitor traffic and amount of impact to vegetation and soils is asymptotic (Cole 1995a, Marion 2016a, Monz et al. 2013). This relationship is examined in greater depth in this section as it has significant implications for the management of visitor use within protected areas.

Above a relatively low threshold of trampling pressure, impacts occur rapidly as plants and organic litter are trampled and lost (Figure 2). This is followed by the exposure and loss of organic soil and compaction of underlying mineral soil. Once the majority of vegetation and litter cover have been lost, soil compaction occurs quickly and

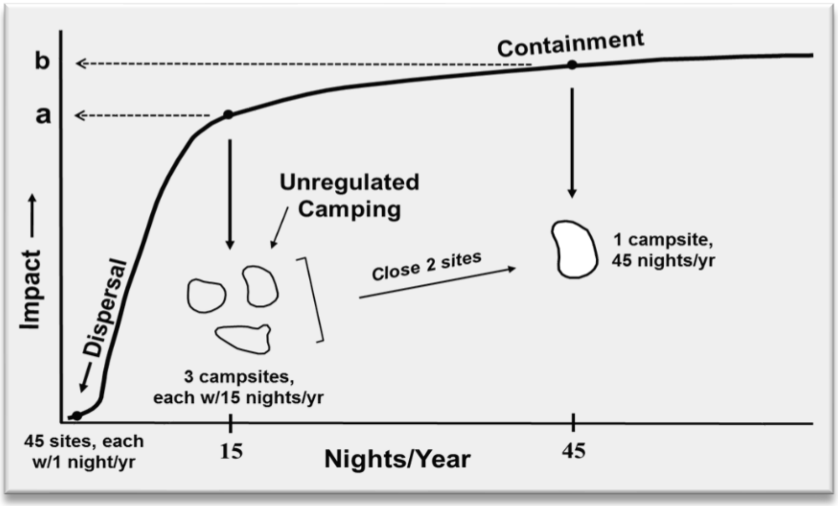


Figure 2. A generalized model of the use-impact relationship for trampling on vegetation and soil illustrating the empirical basis for effective dispersal and containment strategies and why use reduction is often ineffective. Dispersal seeks to prevent the occurrence of lasting impact while containment limits site numbers and aggregate resource impact by concentrating use on a reduced number of sustainable expansion-resistant campsites.

further increases in visitation result in diminishing amounts of vegetation and soil impact. At this point a fundamental management challenge is to constrain the aggregate areal extent of impact by limiting the number and size of recreation sites, and by limiting the width of formal trails and creation of informal trails.

Trail, campsite, and experimental trampling studies have consistently documented this nonlinear asymptotic use-impact relationship between amount of recreational trampling and most types of vegetation and soil impacts (Cole 1995a,b, Hammitt et al. 2015, Monz et al. 2010). This asymptotic use-impact relationship has also been consistently documented in other countries with diverse vegetation and soil types (Barros & Pickering 2015, Hill & Pickering 2009, Littlemore & Barker 2001, Newsome et al. 2013).

The implications of this asymptotic use-impact relationship are that reducing use on well-established moderate- to high-use trails and recreation sites is unlikely to appreciably diminish vegetation and soil impacts; it is an ineffective strategy unless *very* substantial reductions in use occur (Figure 2). In contrast, limiting use within low use areas, where impacts occur rapidly, can lead to substantial reductions in vegetation and soil impact. More specifically, it is effective only at relatively low levels of traffic, generally between 3 and 15 nights of camping per year, or 50 to 250 passes per year along a trail (Leung & Marion 2000, Cole 1995a,b,c).

There are a few important caveats to these general findings. Limitations on the number of visitors or groups during times of peak use (e.g., the annual thru-hiking “bubble” of use) *can* effectively reduce the number or sizes of recreation sites. Recreation sites are often created by visitors during peak use periods, or enlarged by large groups or large numbers of visitors who require more space than afforded on existing sites. Once created, subsequent use of new or enlarged recreation sites, even for just a few days/year, is often sufficient to prevent their recovery (Cole 2013b, Scherrer & Pickering 2006). The timing and location of use also influence the amount of impact that the same number of visitors can have. For example, visitors have substantially greater impact on wet soils compared to dry soils, or on growing plants than on the senesced fall/winter plant remnants. Visitors can also travel or recreate on durable non-vegetated substrates such as gravel, rock, and snow, or artificial substrates like wood and rockwork on trails that support substantial traffic with very limited impact. Finally, Monz et al. (2013) notes the possibility of alternative use-impact response curves for other types of impact, including wildlife responses and aquatic systems that may have differing management implications.

Monz and others (2000) examined large group size impacts in wilderness areas, noting that large groups in a relatively undisturbed area have the potential to create substantial impact on plants and soils unless their activities are sufficiently dispersed. This would suggest that dispersed activities, like camping a single night on unimpacted “pristine” substrates may cause little damage. The authors also note factors that could alter this outcome, including “a group’s level of minimum impact knowledge and behavior” and other factors noted by Newsome (2014).

The curvilinear use-impact relationship suggests that even large groups add little additional impact to existing recreation sites and trails if their activities are concentrated on durable or impacted substrates that are large enough to accommodate them (Monz et al., 2000). Use in off-trail areas must be sufficiently dispersed to prevent the occurrence of lasting resource changes.

Management Guidance

Legislative Mandates

The Appalachian Trail was designated as a national scenic trail by the 1968 National Trails System Act (P.L. 90-543). Administrative responsibility was assigned to the Secretary of the Interior, in consultation with the Secretary of Agriculture. This Act provides little guidance for overnight visitation, with a single reference authorizing: “campsites, shelters, and related public-use facilities.”

The NPS, Appalachian Trail Park Office (ATPO) was given primary administrative authority for the Appalachian Trail (A.T.). This review of A.T. management guidance therefore begins with federal agency legislative mandates, specifically the NPS Organic Act and the Wilderness Act.

The NPS Organic Act of 1916 (16 *United States Code* (U.S.C. 1) established the NPS, directing it to:

> "*promote and regulate the use of the Federal areas known as National Parks, Monuments, and Reservations . . . by such means and measures as conform to the fundamental purpose of the said Parks, Monuments, and Reservations, which purpose is to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations.*"

These provisions were supplemented and clarified by Congress in 1970 and again in 1978 by the “Redwood amendment” (P.L. 95-250, 92 Stat. 163, as amended, 1978) mandating that the “protection, management and administration of these areas shall be conducted in light of the high public value and integrity of the National Park System and shall not be exercised in derogation of the values and purposes for which these various areas have been established..."

The Wilderness Act of 1964 (P.L. 88-577) is also applicable to federal areas through which the A.T. passes. These acts overlay national park and forest designations and are intended by Congress to provide a higher degree of protection for selected areas singled out for exceptional ecological or social value. Wilderness areas are managed under the Wilderness Act to protect their natural resources and processes and to provide visitors with high quality wilderness experiences.

Wilderness is defined by Congress as:

- *an area where the earth and its community of life are untrammeled by man -- where man himself is a visitor who does not remain;*
- *undeveloped federal land retaining its primeval character and influence, without permanent improvements or human habitation;*
- *which is protected and managed so as to preserve its natural conditions;*
- *which generally appears to have been affected primarily by the forces of nature, with the imprint of man's work substantially unnoticeable;*
- *which has outstanding opportunities for solitude or a primitive and unconfined type of recreation*.

The Wilderness Act established the same use and preservation management paradox implied by the Organic Act. Wilderness areas:

> “*shall be administered for the use and enjoyment of the American people in such manner as will leave them unimpaired for future use and enjoyment as wilderness and so as to provide for the protection of*

these areas, the preservation of their wilderness character, and for the gathering and dissemination of information regarding their use and enjoyment as wilderness..."

Agency Guidance

Authority to implement congressional legislation is delegated to agencies, who identify and interpret all relevant laws and formulate management policies to guide implementation. For the NPS, these policies are set forth in Management Policies 2006 (NPS 2006) and other guidelines and manuals.

Congressional legislation directs the NPS to manage visitation contingent upon preserving park environments in an "unimpaired" condition. However, research demonstrates that resources are inevitably changed by recreational activities, even with infrequent recreation by conscientious visitors (Cole 1982 1985, Marion 1984a). What constitutes an impaired resource is ultimately a management decision, a judgment. According to the NPS Management Policies:

> "*The impairment that is prohibited by the Organic Act and the General Authorities Act is an impact that, in the professional judgement of the responsible NPS managers, would harm the integrity of park resources or values, including the opportunities that otherwise would be present for the enjoyment of those resources or values. Whether an impact meets this definition depends on the particular resources and values that would be affected; the severity, duration, and timing of the impact; the direct and indirect effects of the impact; and the cumulative effects of the impact in question and other impacts (section 1.4.5)."*

If interpreted strictly, the legal mandate of unimpaired preservation may not be achievable, yet it serves as a useful goal for managers striving to balance recreation provision and resource protection objectives. Consistent with park purposes, managers are directed to avoid those impacts that can be avoided, and to minimize those that cannot:

> "*NPS managers must always seek ways to avoid, or to minimize to the greatest degree practicable, adverse impacts on park resources and values (section 1.4.3)."*

In backcountry settings, NPS managers are directed to: "identify acceptable limits of impacts, monitor backcountry use levels and resource conditions, and take prompt corrective action when unacceptable impacts occur (section 8.2.2.4)." The number and types of facilities: "will be limited to the minimum necessary to achieve a park's backcountry management objectives and to provide for the health and safety of park visitors."

More specific guidance for wilderness management is contained within federal agency manuals. Information from these sources most relevant to camping management policies are reviewed in this section.

For the NPS, guidance is provided in Director's Order # 41, Wilderness Preservation and Management (NPS 1999). Recreational uses of wilderness should be those traditionally associated with wilderness and that will leave the area unimpaired. Management should provide for outstanding opportunities for solitude or primitive and unconfined types of recreation (section 6.4.3). The construction of new shelters for public use is not generally allowed, though existing shelters may be maintained or reconstructed if the facility is determined to be necessary to achieve wilderness management objectives identified in the park's management plans (section 6.3.10.3).

Campsite facilities may include a site marker, fire rings, tent sites, food storage devices, and toilets if these are determined to be necessary for the health and safety of visitors or the preservation of wilderness resources and values. Toilets can be used only where their presence will resolve health and sanitation problems or prevent serious resource impacts (section 6.3.10.3). Only signs needed for visitor safety or to protect wilderness resources are permitted (section 6.3.10.4).

For the USFS, guidance is provided in their manual #2300-90-2, Recreation, Wilderness, and Related Resource Management (Forest Service 1990). Recreation use should be consistent with management of the area as wilderness through experiences that depend on a wilderness setting (section 2323.11). Managers are to maximize visitor freedom and minimize direct controls and restrictions within the wilderness. Information and education should be the primary visitor management tools, with more restrictive measures applied only when essential for protecting wilderness resources (section 2323.12).

No new camping shelters may be constructed, though those that existed at the time of designation may be maintained if allowed by specific legislation, or until they require extensive maintenance (sections 2323.13 & 2323.13b). Generally, facilities are installed only as a last resort and only for protection of the wilderness resource. Managers are directed to relocate or remove unnecessary campsites to allow maximum opportunity for solitude and to minimize the evidence of human use. However, designation of campsites is considered a "last resort" action (section 2323.13a).

The "cat hole" method of human waste disposal is recommended, though pit or vault toilets may be used if necessary. Sign use should be minimal; justified for either the routing or location of the traveler or the protection of the wilderness resource.

The 1978 amendment to the National Trails Act directed the federal agencies to prepare a Comprehensive Plan for the Appalachian Trail, approved by the NPS and USFS in 1981 (NPS 1981). This plan contains a single, brief reference to overnight-use management:

> "*Shelters are a tradition on the A.T., but use of the Trail should not depend upon them. No attempt is made to provide such amenities for every potential user, so each person must be prepared to do without them. Shelter density and design should be consistent with the sense of the natural."*

The NPS also has developed several policies that apply to overnight-use areas located on NPS lands acquired for the Appalachian Trail:

> "***Designated or Dispersed Camping*** *- In July 1986, the NPS Appalachian Trail Park Office adopted the following regulation under its regulatory authority in 36 CFR 2.10: "On NPS-acquired Trail lands, camping will remain dispersed except where camping is limited to specific camping and/or shelter sites by ATC member Trail clubs in their local management plans and these plans are endorsed by ATC." Camping policy on NPS corridor lands should be consistent, to the extent feasible, with the policies on adjacent lands to minimize confusion and enhance understanding and coordination between jurisdictions."*
>
> *"**Environmental Compliance** - On NPS corridor lands, new shelters and large campsites with more than one pit privy must be evaluated by the NPS in an environmental assessment prior to any clearing, excavation, or construction by the club. Improvements to existing shelters and installation of new campsites with one pit privy do not normally require an environmental assessment; they are "categorically excluded" from compliance with NEPA (Federal Register, Vol. 49, No. 194, October 4, 1984)."*

Guidance may also be found in the management plans of federal and state agencies that manage lands bisected by the A.T. corridor. For example, the Backcountry Management Plan for Great Smoky Mountains NP (NPS 1993) provides for the continuation of shelters and when they are full, permits thru-hikers to camp in the immediate vicinity (section 2.7-2.9). The Backcountry and Wilderness Management Plan for Shenandoah NP (NPS 1998) assigned a special park zone to the A.T. corridor. The plan employs the Recreational Opportunity Spectrum framework with zone descriptions of resource, social, and managerial settings and addresses carrying capacity through application of a modified Limits of Acceptable Change decision framework. Relative to camping, the plan provides for continuation of existing huts and cabins. Designated campsites are permitted at huts, but groups should be out of sight and sound of each other at campsites along the trail.

USFS guidance is provided in regional manuals and in each forest plan. The USFS *Regional Standards and Guides for Region 8* state:

> "*Trail shelters and related facilities will be managed, constructed and maintained in accordance with ATC's Overnight Use Principles and the responsible A.T. club local management plan. Primitive camping will be encouraged at appropriate sites, but not within 100 feet of the Trail."*

Proposals for new shelters and designated campsites need to be evaluated and, in most cases, environmental assessments must be prepared and approved before work proceeds.

State and local guidance must also be investigated and followed. For example, local building codes, sanitation regulations, and fire laws must be complied with and state agencies must approve shelters and campsites on state-owned lands (ATC 1997).

Appalachian Trail Conference Guidance

The ATC has developed the most specific guidance for managing overnight visitation along the A.T. This guidance is contained in numerous documents which are cited and summarized in this section. ATC policy for managing overnight use on the A.T. is contained within the *Local Management Planning Guide* (ATC 1997), which provides a comprehensive reference to volunteer Trail clubs and guidance for developing local management plans, required for each participating club. Chapter 2 (F), *Overnight-Use Areas*, states:

> *"Since 1925, ATC policy has supported "a connected series of primitive lean-tos and camps" as an integral part of the Trail experience. ATC policy is to perpetuate and improve the shelter and campsite system with well-located, -designed, -constructed, and -maintained facilities. Proposed facilities should comply with the National Environmental Policy Act (NEPA), Section 106 of the National Historic Preservation Act, and state and local building and health codes and environmental laws..."*

In November 2007 new overnight visitation policies were adopted: "Guidance for Locating and Designing A.T. Shelters and Formal Campsites." These require that shelters and large formal campsites be approved by the ATC and land management agencies through a formal process that considers their capacity, location, and design.

A broader, visionary statement guiding A.T. management is provided by the ATC's Board of Managers, who defined the desired Trail Experience as:

> *"The sum of opportunities that are available for hikers on the Appalachian Trail to interact with the wild, scenic, pastoral, cultural, and natural elements of the environment of the Appalachian Trail, unfettered and unimpeded by competing sights or sounds, and in as direct and intimate a manner as possible. Integral to this Trail Experience are opportunities for observation, contemplation, enjoyment, and exploration of the natural world; a sense of remoteness and detachment from civilization, opportunity to experience solitude, freedom, personal accomplishment, self-reliance, and self-discovery; a sense of being on the height of the land; a feeling of being part of, and subordinate to, the natural environment; and opportunity for travel on foot, including opportunities for long-distance hiking."*

More specific ATC publications that guide management of overnight visitation, include Overnight Use Principles (ATC 1977), the Appalachian Trail Fieldbook (Birchard & Proudman 2000), and Guidelines for sanitation, water supplies, and overnight facilities along the Appalachian Trail on National Forest lands (ATC undated).

Volunteer Trail Club Guidance

As directed by Congress, the Comprehensive Plan for the Appalachian Trail (NPS 1981) prescribes a "Cooperative Management System" of partnerships with individual trail clubs and agency partners in a decentralized consultation and decision-making process. Currently, there are 31 trail clubs that manage and maintain separate Trail segments in cooperation with the ATC and agency partners. As described in the ATC's Local Management Planning Guide, each club must prepare an approved management plan for their trail segment(s). These plans often include area-specific guidance on managing overnight visitation at both shelters and campsites. For example, plans may designate areas that are closed to camping, open to dispersed camping, designated campsites, or campfire prohibitions. ATC regional offices and trail clubs also maintain inventories of overnight use facilities and track their condition over time. Maintenance plans for shelters and action plans for constructing new shelters are also developed by local trail clubs.

Carrying Capacity Decision-Making

As reviewed in Marion (2016a), the traditional body of knowledge developed by managers and scientists to address the negative impacts of visitation to resource and social conditions was termed "carrying capacity." While the early management activity and literature focused on defining a numeric limit on visitor numbers below which resource and social conditions would be protected, several decades of management and research experience have exemplified the curvilinear use-impact relationship illustrated in Figure 2, demonstrating that amount of use is strongly correlated with the magnitude of resource impact only at low levels of use. Thus, limiting use is often an ineffective means for achieving resource protection objectives on moderate to high use trails and recreation sites, prompting the need to consider a diverse array of alternative considerations and actions (Leung & Marion 2000, Manning 2007, 2011, Wagar 1964). This is widely accepted in the context of minimizing resource impacts, though court challenges based on dated laws specifying the role that numerical limits should play in carrying capacity planning continue to focus management attention on visitor numbers (Capacity Work Group 2010, Graefe et al. 2011, Whittaker et al. 2011).

Instead of an emphasis on amount of use, research increasingly points to strong influence of a diverse array of use-related, managerial, and environmental factors affecting resource and social/experiential impacts (Marion & Leung 2004, Marion 2016a, Marion et al. 2016):

- Use-related factors include attributes like the number visitors, the types of activities they are engaged in, the locations where activities occur, and the extent to which visitors know and apply low impact behaviors.
- Managerial factors include the presence and physical size/capacities of facilities (e.g., campsites, shelters, formal trails and their widths), the types of facilities and level of containment (e.g., trails and recreation sites in flat vs. sloping terrain, presence of containment borders like logs or scree walls), durability of substrates (e.g., vegetation, soil, wood, gravel, rock), regulations and enforcement, existence/efficacy of low impact education efforts.
- Environmental factors include the resistance and resiliency (ability to recover) of soils and vegetation, weather (vegetation and soil impacts increase with increasing soil moisture), topography, and to the presence of water resources and wildlife, and their sensitivity to human impact.

Particularly influential factors that minimize resource impacts demonstrated in scientific studies include:

1) sustainable siting and designs for recreation sites and trails relative to topography and soil/vegetation type,
2) actions that spatially concentrate activity to a limited "footprint" of disturbance, and
3) regulations and persuasive communication that promote low impact behaviors and reduce the number of People At One Time (PAOT) within single locations or small areas (Cole 1989b, Hammitt et al. 2015, Leung and Marion 2000, Marion 2014).

Similar findings have been identified for social impacts like crowding and conflict, such as the significant influence of visitor motives, use type, user behavior, and the density of use and location or timing of encounters (Manning 2007, 2011).

Of particular concern to the A.T. community is the annual thru-hiker "bubble" of use and special events like Trail Days at Damascus or "trail magic" hiker feeds that involve large numbers and densities of participants with the potential to exceed the physical, resource, or social capacities of the A.T. Many A.T. facilities, such as trailhead parking lots, campsites, and shelter-associated camping areas, have fixed physical capacities that can be permanently expanded with more than a few nights of use by particularly large numbers of visitors or large group events (i.e., high PAOT). Even a few nights of use each year in newly expanded areas prevents their recovery. Similarly, adding large numbers of visitors from special events or the thru-hiker bubble to the existing A.T. infrastructure of recreation sites and formal trails can cause overflow traffic in adjacent undeveloped areas where resource impacts may quickly occur. Such periods of high PAOT can also create problems with visitor crowding and conflicts between event participants and regular A.T. visitors, leading to their displacement or reduced satisfaction. These resource and social concerns all relate to visitor carrying capacity, a concept that park managers are required to address in their planning and management decision-making, and for which there is agency guidance.

NPS *Management Policies* (2006) defines carrying capacity as, "the type and level of visitor use that can be accommodated while sustaining the desired resource and visitor experience conditions in the park. By identifying and staying within carrying capacities, superintendents can prevent park uses that may unacceptably impact the resources and values for which the parks were established." These policies additionally state that:

> *"When making decisions about carrying capacity, superintendents must utilize the best available natural and social science and other information, and maintain a comprehensive administrative record relating to their decisions. The decision-making process should be based on desired resource conditions and visitor experiences for the area; quality indicators and standards that define the desired resource conditions and visitor experiences; and other factors that will lead to logical conclusions and the protection of park resources and values.*
>
> *The general management planning process will determine the desired resource and visitor experience conditions that are the foundation for carrying capacity analysis and decision-making. If a general management plan is not current or complete, or if more detailed decision-making is required, a carrying capacity planning process … should be applied in an implementation plan or an amendment to an existing plan.*
>
> *As use changes over time, superintendents must continue to decide if management actions are needed to keep use at acceptable and sustainable levels. If indicators and standards have been prescribed for an impact, the acceptable level is the prescribed standard. If indicators and standards do not exist, the superintendent must determine how much impact can be tolerated before management intervention is required. (Section 8.2.1)."*

Many managers will already have considered or made carrying capacity decisions in a general management plan. The 1978 National Parks and Recreation Act (P.L. 95-625) requires the NPS to determine carrying capacities for each park as part of the process of developing management plans. Specifically, amendments to Public Law 91-383 (84 Stat. 824, 1970) require relevant NPS management plans to include "identification of and implementation commitments for visitor carrying capacities for all areas of the unit" and determination of whether park visitation patterns are consistent with social and ecological carrying capacities.

Carrying capacity has long provided the predominant framework for planning and management decision-making that addresses the protection of natural resource and social conditions (Manning 2011). Over time, managers have shifted from a narrow focus on numeric carrying capacity to a broader decision-making framework that incorporates a more comprehensive array of management strategies and actions (Graefe et al. 2011). As directed by the NPS *Management Policies*, carrying capacity determination and management should be developed through an adaptive management process. In its simplest form adaptive management means learning by doing, and adapting based on what's learned (Williams and Brown 2012). A more formal definition is "… flexible decision making that can be adjusted in the face of uncertainties as outcomes from management actions and other events become better understood. Careful monitoring of these outcomes both advances scientific understanding and helps adjust policies or operations as part of an iterative learning process" (National Research Council 2004).

Visitor Use Management

Recently, six U.S. federal agencies – the Bureau of Land Management, Forest Service, National Oceanic and Atmospheric Administration, NPS, U.S. Army Corps of Engineers, and U.S. Fish and Wildlife Service – formed an Interagency Visitor Use Management Council (IVUMC; http://visitorusemanagement.nps.gov/) to "increase awareness of and commitment to proactive, professional, and science-based visitor use management on federally-managed lands and waters." They have developed a new Visitor Use Management (VUM) framework focused on managing visitor use to protect resources and provide high quality experiences, with numeric carrying capacity determinations included as an option when needed or required by law. Its attributes include prescriptive management objectives that define desired resource and social conditions, selection of indicators and thresholds (standards) specifying the limits of acceptable change, monitoring to compare current conditions to standards, and implementation and evaluation of corrective management actions.

Comprehensive guidance for implementing VUM is available at the IVUMC website, including several publications. They define VUM as the "proactive and adaptive process for managing characteristics of visitor use and the natural and managerial setting using a variety of strategies and tools to achieve and maintain desired resource conditions and visitor experiences." They emphasize that managing visitor access and use for recreational benefits and resource protection is inherently complex, requiring consideration of natural and social science studies, management experience, and professional judgment. Guidance for implementing VUM, depicted in Figure 3 was released in 2016 for use by all federal land management agencies for managing visitor use and carrying capacity. It is expected to be widely adopted across U.S. protected areas and the A.T. community has already proceeded with its implementation in high use/high impact areas.

VUM incorporates lessons learned from agency experience to address past planning and legal challenges (Graefe et al. 2011, Whittaker et al. 2011). VUM incorporates additional guidance for carrying capacity decision-making when needed, but its primary focus is on visitor use management topics. Because VUM provides a defensible and adaptive management decision-making framework, it offers an effective and efficient process that the A.T. community could apply for evaluating and managing all aspects of visitor use, including determinations of carrying capacities and the management of special events and the thru-hiker bubble.

The *Visitor Use Management Framework: A Guide to Providing Sustainable Outdoor Recreation* (IVUMC 2016) describes the VUM framework in more detail:

> *"This framework will enhance consistency in visitor use management on federally managed lands and waters, since it will be used by all agencies. The elements of this framework are broadly applicable to all visitor use management issues and opportunities. The framework is applicable across a wide spectrum of situations that vary in spatial extent and complexity, from site-specific decisions to large-scale comprehensive management plans. This framework may also be used across multiple, tiered projects and may be applied to internally driven activities (e.g., analyzing a management action), as well as externally driven activities (e.g., a permit request or an action by another agency)."*

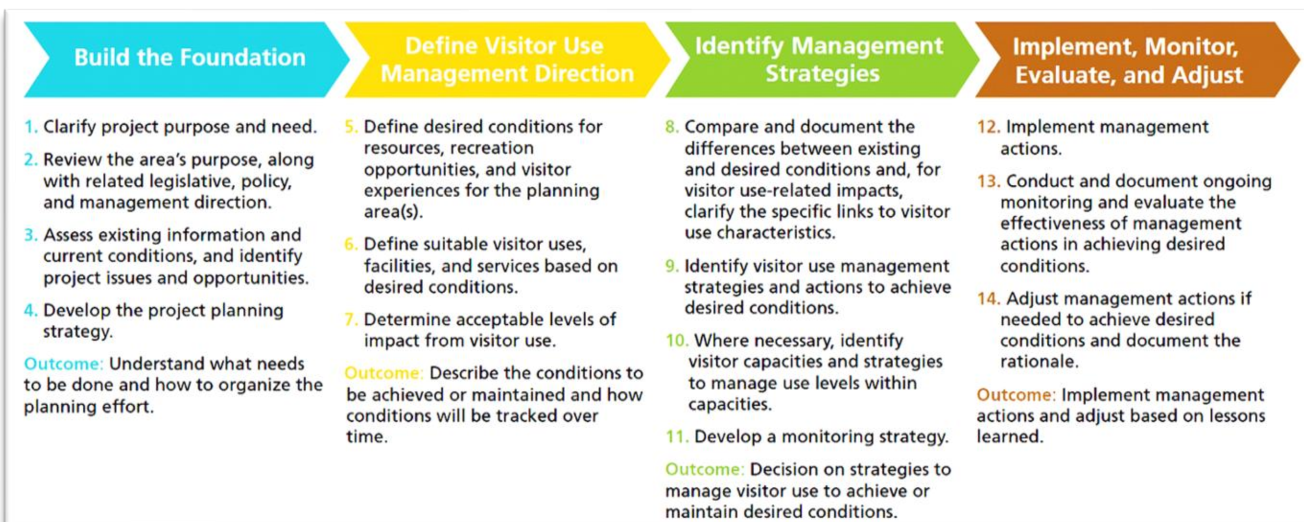


Figure 3. The Visitor Use Management (VUM) framework recommended by the IVUMC for adaptively managing visitor use and carrying capacities in protected natural areas.

The strengths of this framework are that it is “iterative, adaptable and flexible” to a variety of environmental settings and scales (IVUMC 2016), and that it embraces a “sliding scale” concept to optimize the efficiency of the framework’s application:

> *“Applying different levels of analysis can be likened to using a sliding scale in which one end of the scale requires a low level of analysis and the other a high level of analysis. In either case, the analysis still must satisfy all framework requirements. It is the investment of time and resources that varies along the sliding scale, not the elements in the framework; the same fundamental elements are used regardless of the placement on the scale.*
>
> *This sliding scale approach is consistent with direction given in the Council on Environmental Quality’s interpretation of NEPA. This approach implements the instruction that agency NEPA documents shall “focus on significant environmental issues and alternatives” (40 CFR 1502.1) and shall discuss impacts “in proportion to their significance” (40 CFR 1502.2(b)).* (Note: Under the Council on Environmental Quality’s regulations and judicial rulings, the degree to which environmental effects are likely to be controversial with respect to technical issues is a factor in determining significance.)”

Applying this “sliding scale of analysis” seeks to match the investment made in analysis with the level of complexity and risk associated with the issues being addressed. For this reason, the VUM framework can provide structure to trail-wide or location-specific resource and social impacts, or to the management of temporal problems like the thru-hiker bubble or special events.

IVUMC places substantial emphasis on “proactive, professional, and science-based visitor use management on federally-managed lands and waters.” Managers who make proactive decisions should be prepared to prove the viability of their strategies, or risk public disapproval or even legal action against the agency. Resource and visitor use monitoring programs provide the means for such demonstrations. Current legislation and agency documents establish mandates for monitoring, which is reviewed in the following section (Marion 1991). Recent legislative mandates allow managers more latitude to make proactive decisions that can be defended in the court of law or public opinion, when necessary.

Monitoring Visitor Impacts

This section reviews relevant NPS laws and management policies pertaining to resource monitoring. Formal or informal monitoring is generally conducted to evaluate the occurrence and acceptability of resource impacts associated with visitor use and is generally an essential component of decision-making frameworks like VUM.

The National Parks Omnibus Management Act of 1998 established a framework for fully integrating natural resource monitoring and other science activities into the management processes of the National Park System. The Act charges the Secretary of the Interior to:

> *"develop a program of inventory and monitoring of National Park System resources to establish baseline information and to provide information on the long-term trends in the condition of National Park System resources."*

Congress reinforced the message of the National Parks Omnibus Management Act of 1998 in its text of the FY 2000 Appropriations bill:

> *"A major part of protecting [park] resources is knowing what they are, where they are, how they interact with their environment and what condition they are in. This involves a serious commitment from the leadership of the National Park Service to insist that the superintendents carry out a systematic, consistent, professional inventory and monitoring program, along with other scientific activities, that is regularly updated to ensure that the Service makes sound resource decisions based on sound scientific data."*

Relative to the need for balancing visitor use and resource impacts, the NPS *Management Policies* (2006) state that:

> *"The "fundamental purpose" of the national park system, established by the Organic Act and reaffirmed by the General Authorities Act, as amended, begins with a mandate to conserve park resources and values. This mandate is independent of the separate prohibition on impairment, and so applies all the time, with respect to all park resources and values, even when there is no risk that any park resources or values may be impaired. NPS managers must always seek ways to avoid, or to minimize to the greatest degree practicable, adverse impacts on park resources and values.*

Monitoring programs are also 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". (*Section 4.1*)
>
> "Further, The Service will:

- *Identify, acquire, and interpret needed inventory, monitoring, and research, including applicable traditional knowledge, to obtain information and data that will help park managers accomplish park management objectives provided for in law and planning documents.*
- *Define, assemble, and synthesize comprehensive baseline inventory data describing the natural resources under its stewardship, and identify the processes that influence those resources.*
- *Use qualitative and quantitative techniques to monitor key aspects of resources and processes at regular intervals.*
- *Analyze the resulting information to detect or predict changes, including interrelationships with visitor carrying capacities, that may require management intervention, and to provide reference points for comparison with other environments and time frames.*
- *Use the resulting information to maintain-and, where necessary, restore-the integrity of natural systems" (Section 4.2.1).*

Thus, relative to visitor use management, park managers must evaluate the types and extent of resource impacts associated with visitor activities and determine to what extent they are unacceptable and constitute impairment. Further, managers must seek to avoid or limit any form of resource impact, including those judged to fall short of 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 specific impacts to natural resources.

NPS has directives for carrying capacity decision-making, adaptive management, and monitoring as a tool to accomplish management goals. If managers are to avoid unacceptable visitor impacts to the park resources and experiences it is clear they should be focused, purposeful and proactive in their decisions. The application of the VUM framework offers an efficient structured process that can guide decisions. Again, the sliding scale of analysis offered by VUM means managers can provide any level of structure needed for evaluating and managing visitor impacts on a scale appropriate to the problem.

Table 2 includes a list of common A.T. facilities and resources and some core types of experiential and resource impacts associated with high visitation. As an example, consider a large annual "trail magic" hiker feed event located at an A.T. shelter and camping area. Such events often cause dispersed thru-hikers to regroup and "bunch up" again for a period of time. The resulting a bubble of hikers could exceed overnight camping capacity at both the event shelter and neighboring camping areas north and south along the A.T. Exceeding local camping capacities often leads to the permanent creation of new campsites or the expansion of existing campsites. Parking capacity may also be exceeded at the nearest trailhead, displacing day-hikers and weekend backpackers. The dissimilar nature of the event, which may involve alcohol, music/noise, and large groups, contributes to visitor crowding, conflicts, and the spatial or temporal displacement of "regular" A.T. visitors. Similar social and resource impacts could also occur along A.T. or at adjacent vistas, water sources, and swimming holes, which could be used at levels exceeding their inherent physical capacity. Substantial overuse of toilets and food storage devices, and of adjacent off-trail areas could cause additional resource impacts to vegetation, soil, wildlife, and water resources.

Table 2. A.T. facilities and resources and some potential visitor experiential and resource impacts of concern.

Facility or Resource Affected	Potential Impacts to Consider
Trailhead Parking	Visitor displacement/crowding/conflicts, vehicle impacts to overflow parking areas and road shoulders.
Day-Use and Overnight Recreation Sites	Visitor displacement/crowding/conflicts; facility overuse, resource impacts, site proliferation, site expansion.
Formal Trails	Visitor displacement/crowding/conflicts; resource impacts, particularly trail widening & off-trail degradation.
Off-trail, Off-site Resources	Trampling impacts to vegetation, soil, & water resources; informal trail and recreation site creation/proliferation, wildlife disturbance.

Visitor impact monitoring protocols are often developed by scientists to provide accurate and precise data on physical attributes (e.g., trail width or campsite size), vegetation cover, tree damage, and soil exposure, loss, or muddiness (Marion 1991, Cole 2006). Thorough reviews of the visitor impact monitoring literature, assessment methods, and examples of monitoring indicators can be found in publications for formal trails (Dixon et al. 2004, Hawes et al. 2006, Hill and Pickering 2009, Marion and Carr 2009, Marion and Leung 2011, Marion et al. 2006, 2011a), informal (visitor-created) trails (Leung and Louie 2008, Leung et al. 2011, Marion and Wimpey 2011, Marion et al. 2011a, b), and recreation sites and campsites (Cole 2013a, Cole and Parsons 2013, Marion & Leung 2001, Marion and Hockett 2008, Newsome et al. 2013).

Many of the cited publications are reports that contain full sets of field assessment protocols that can be applied or adapted into visitor impact monitoring programs. We suggest careful attention to select protocols that can be efficiently applied, provide quantitative data, are focused on key indicators reflecting desired conditions, and are sensitive to the changes expected from special use events. We note that monitoring data can provide beneficial information needed for adaptive management decision-making. More guidance is included in the following section and in this report's Discussion section and Appendices.

Monitoring Indicators and Selection Criteria

Indicators are defined as managerially relevant measurable physical, ecological, or social variables used to track trends in conditions caused by human activity so that progress toward goals and desired conditions can be assessed. An indicator is any setting element that changes in response to a process or activity of interest (Merigliano 1990). An indicator's condition over time provides a gauge of how recreation has changed a setting. Comparison to management objectives or indicator thresholds (standards) reveals the acceptability of any resource changes. Indicators provide a means for restricting information collection and analysis to the most essential elements needed to answer management questions such as:

- Are visitors experiencing an environment where the evidence of human activity is substantially unnoticeable?

- Are trail and recreation site conditions acceptable given each management zone's objectives and desired conditions?
- Are management practices effective in minimizing the creation or degradation of informal trails and recreation sites, or degradation of their formal counterparts?

Before a monitoring program can be developed, appropriate resource indicators must be selected. A single, direct measurement of a trail's condition is inappropriate because the overall condition is an aggregate of many components. Typically, then, monitoring evaluates various soil, vegetation, or aesthetic elements of a trail that serve as indicators of that facility's condition. Cole (1989c), Marion (1991) and Merigliano (1990) review criteria for the selection of indicators (Table 3), which are summarized here. Management information needs, reflected by the management questions such as the examples above, guide the initial selection of indicators.

Preferred indicators should reflect attributes that have ecological, experiential, or managerial significance. Indicator measures should primarily reflect changes caused by the recreational activity of interest. For example, measures of soil loss related to trail construction would be inappropriate. Indicators should be measurable, preferably at an interval or ratio scale where the distances between numeric values are meaningful, i.e. a 36-inch wide trail is twice the width of an 18-inch trail. In comparison, a categorical ratings system based on subjective assessments rather than measures provides data at an ordinal scale. Distance between categorical values are not meaningful so computing an average is inappropriate, though non-parametric procedures can be used to evaluate changes.

Table 3. Criteria for selecting indicators of resource condition.

Criteria	Rationale
Quantitative	Can the indicator be measured?
Relevant	Does the indicator change as a result of the process or activity of interest?
Efficient	Can assessments be applied by available staff within existing time and funding constraints?
Reliable	How precise are the measurements? Will different individuals obtain similar data?
Responsive	Will management actions affect the indicator?
Sensitive	Does the indicator act as an early warning, alerting you to deteriorating conditions before unacceptable change occurs?
Integrative	Does the indicator reflect only its condition or is its condition related to that of other, perhaps less feasibly measured, elements?
Significant	Does the indicator reveal relevant environmental or social conditions?
Accurate	Will the measurements be close to the indicator's true condition?
Understandable	Is the indicator understandable to non-professionals?
Low Impact	Can the indicator be measured with minimal impact to the resource or visitor experiences?

Adapted from Cole (1989c), Marion (1991), Merigliano (1990).

Potential indicators of resource condition are numerous and there is great variation in our ability to measure them with *accuracy*, *precision*, and *efficiency*. All assessments are approximations of an indicator's true value; a measurement method is *accurate* if it closely approximates the true value. A measurement method is *precise* if it consistently approximates a common value when applied independently by many individuals (i.e., repeatability). Accurate measurements correctly characterize current conditions; precise measurements allow valid comparisons of change over time (Cole 1989c, Marion 1991). *Efficiency* refers to the time, expertise, and equipment needed to measure the indicator's condition.

When choosing a method (protocol), managers must balance accuracy and precision, for each places constraints upon efficiency and cost-effectiveness. For example, recreation site condition assessments range from highly efficient but subjective evaluations (e.g., condition class ratings), to rapid assessments (ratings based on numeric categories of damaged trees), to time-consuming research-level measurements (quadrat-based vegetation loss assessments). Regardless of the method selected, comprehensive procedural manuals, staff training, and program supervision stressing quality control can improve both accuracy and precision. However, poorly managed monitoring efforts can result in measurement error that confounds data interpretation or even exceeds the magnitude of impact caused by recreational activities.

Preferred Indicators

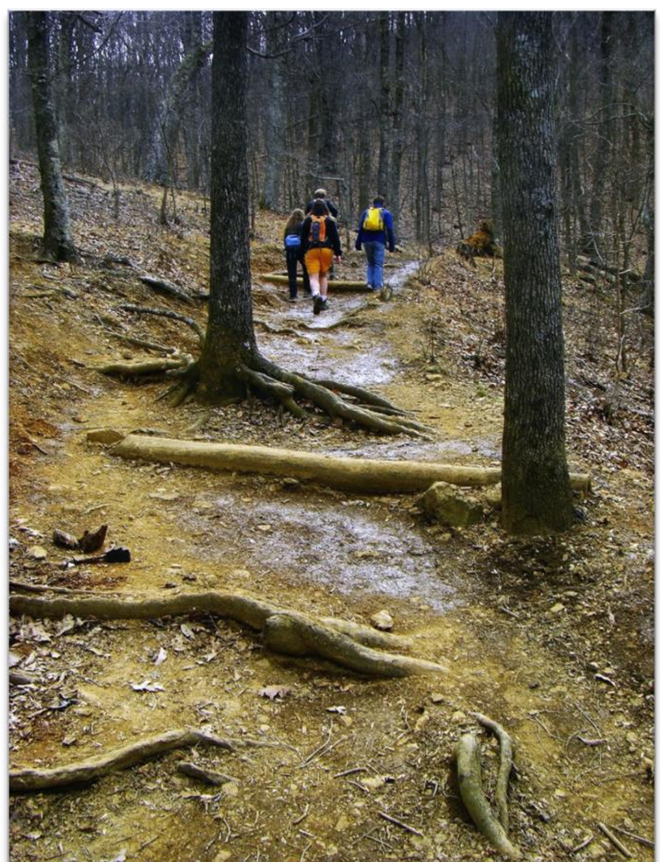
From these indicator criteria and knowledge of how recreation affects soil, vegetation, and aesthetics, managers select preferred indicators. Table 4 includes a listing of commonly employed indicators for assessing resource conditions on trails and recreation sites using measurement-based approaches. Generally, a small number of indicators are selected for use in visitor use management frameworks. However, that does not preclude monitoring of additional resource condition indicators or from also assessing various inventory indicators. Travel time to the sampling locations is often the most substantial portion of the time budget so assessing a few additional indicators can be negligible.

Table 4. Potential indicators of trail and recreation site conditions and measurement units.

Trail Indicators	**Measurement Units**
Informal Trails	Length/unit area, % of formal trail length, #/unit length on formal trails, degree of fragmentation of unit area
Tread Width	Max. value, value/unit length, running avg./unit length
Maximum Incision	Max. value, value/unit length, running avg./unit length
Muddiness	Max. % of tread width, avg. %/unit length, running avg. %/unit length
Campsite Indicators	**Measurement Units**
Informal Recreation Sites	#/unit area, #/unit length along formal trails
Site Size	Max. value, value/unit area, aggregate value/unit area
Area of Vegetation Loss	Max. value, value/unit area, aggregate value/unit area
Area of Soil Exposure	Max. value, value/unit area, aggregate value/unit area
Damaged Trees	Max. value, value/unit area, aggregate value/unit area
Fire Sites	Max. value, value/unit area, aggregate value/unit area
Litter	Max. value, value/unit area, aggregate value/unit area
Human Waste	Max. value, value/unit area, aggregate value/unit area

Indicator measures that are collected with Global Positioning System (GPS) waypoints allow greater flexibility in analyses at different spatial scales and comparisons across park zones or other strata. A final consideration is the measurement unit employed for reporting results and/or setting standards. Measurement-based approaches permit the most flexibility in this respect. For example, soil loss can be assessed at sample points by measuring maximum incision along a transect, with standards specifying maximum allowable values (Cole 1983, Marion et al. 2006). Standards could also be expressed as a value per unit length or per unit area, or as a running average per unit length.

In summary, managers must consider and integrate a diverse array of issues and criteria in selecting indicators for monitoring impacts on trails and recreation sites. Indicators will rarely score high on all criteria, requiring good judgment as well as area-specific field trials and direct personal experience. Tradeoffs are also required, such as a necessary reduction in accuracy so that precision and efficiency may be increased.



STUDY AREA

The A.T. is a 2,190-mile continuous footpath stretching from Springer Mountain, Georgia to Mount Katahdin in Maine (Figure 4). The trail is marked with white blazes and traverses the Appalachian Mountain range through 14 states, 6 NPS units (33% of the trail), 8 National Forests (47% of the trail), and a suite of more than 80 state and local jurisdictions (NPS 2008, 2015). The A.T. receives an estimated three million visitors/year, supporting day hikes, weekend backpacking and camping trips, section-hikes, and thru-hikes of the entire trail in a single year (ATC 2018). More than half of the U.S. population resides within a day's drive from the A.T. and its visitation has increased substantially in the past decade.

The A.T. was originally proposed in 1921 by regional planner Benton MacKaye to create a corridor of protected natural landscapes and recreation opportunities accessible to major population centers along the Eastern United States (NPS 2015). Construction began in Harriman and Bear Mountain State Parks in 1923 and a continuous footpath from Maine to Georgia was established by 1937. The A.T. was designated as our nation's first National Scenic Trail in 1968 as a unit of the NPS. Final federal land acquisition to fully protect the A.T. corridor was completed in 2014 with a land base of more than 250,000 acres (NPS 2015). A.T. management responsibilities are shared through a unique collaborative partnership with the Appalachian Trail Conservancy (ATC), federal, state, and local land managers, and 31 volunteer trail clubs (NPS 1981). In 2017, 5,939 individuals contributed 239,798 hours toward the maintenance, improvement and construction of A.T. assets (ATC 2018).

The ATC is comprised of four management regions: 1) SORO – Georgia, North Carolina, and Tennessee, 2) VARO – Southwest and Central Virginia, 3) MARO – Mid-Atlantic, and 4) NERO – Connecticut, Massachusetts, Vermont, New Hampshire, and Maine. Regional ATC staff work directly with land managers, club members, and other organizations on all aspects of A.T. stewardship and management.

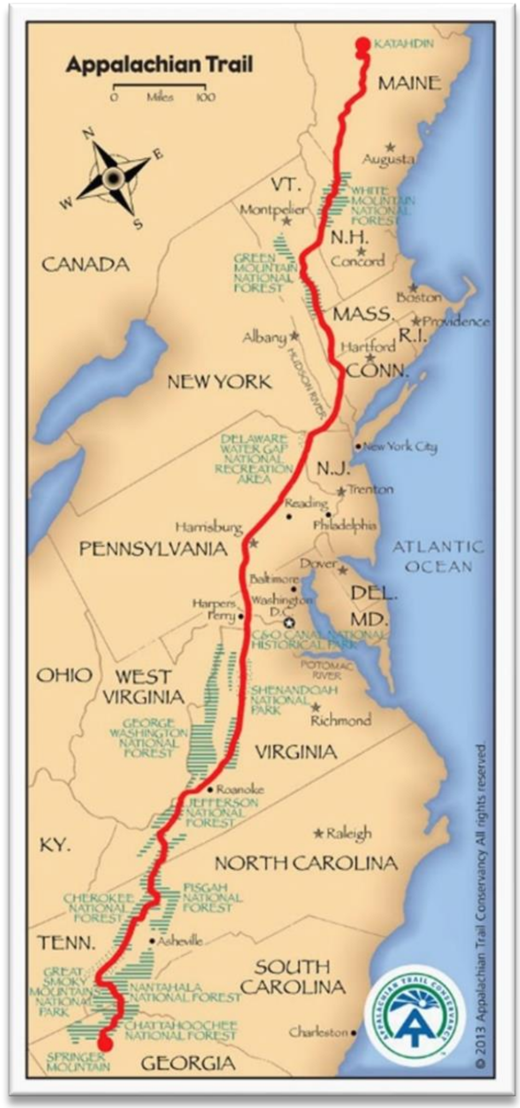
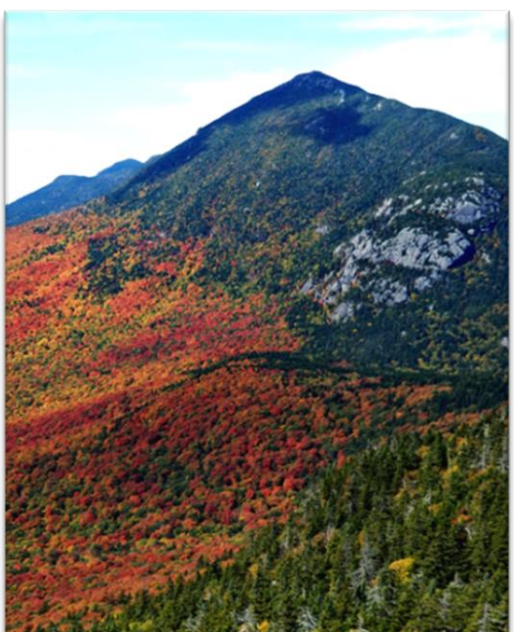


Figure 4. The 2,190-mile Appalachian National Scenic Trail crosses 13 states.

The A.T. corridor connects a variety of land designations, including 25 federally designated Wilderness areas (150 miles, 7% of the trail), backcountry, rural agricultural areas, and accessible frontcountry. The A.T. traverses five major geologic sub-provinces of the Appalachian Mountains, including some of the oldest geologic strata in the world characterized by fold and thrust marine sedimentary rocks, volcanic rocks, and slivers of ancient ocean floor (NPS, 2008). The protected corridor includes a wide range of latitudinal, elevational and moisture gradients that support diverse assemblage of flora and fauna and protect watersheds that provide significant ecosystem services (NPS, 2008). The A.T. passes through 14 major forest types, including rare alpine and subalpine vegetation communities, spruce-fir, and northern hardwood forests in the North, to hickory, oak and mixed hardwood forests in the South (NPS 2008). While predominantly forested, the A.T. also traverses grassy balds and treeless high-elevation vegetation communities with elevations ranging from 125-6624 ft.

The A.T. corridor protects populations of nine federally-listed and 360 state-listed species of rare plants and animals (ATC 2018). Inventories have documented more than 1,700 occurrences of globally or regionally rare species and rare or exemplary communities in more than 500 Natural Heritage Sites within the A.T. corridor. More than 80 globally rare plant community types have been identified along the trail, including rare and fragile high elevation spruce/fir forests and Southern Appalachian mountain bogs – two of the most endangered ecosystems in the United States. The A.T. corridor also serves as a migratory corridor for a myriad of species and connects some of the largest remaining tracts of undeveloped wildlands in the Appalachian Mountains.

The narrow A.T. corridor, averaging only 1000 feet in width, means that natural heritage sites, rare species, and sensitive plant communities are frequently close to and affected by visitor trampling associated with the trail, shelters, campsites, and day-use recreation sites. Camping management along the A.T. is diverse, with dispersed, established, and designated site camping at approximately 4000 campsites (5600 as estimated by this current study), and at more than 250 shelters spaced approximately eight miles apart (ATC 2018). A survey of A.T. visitors found that 56% of the overnight visitors stayed in shelters, 12% camped near shelters, 23% stayed at established or designated campsites, and 9% camped elsewhere along the trail (Manning et al. 2000). Camping regulations and guidance vary considerably due to the numerous management agencies involved (Camping on the AT), though land managers and volunteers have adopted consistent low impact outdoor practices advocated by the national Leave No Trace program (Leave No Trace on the AT) (Marion 2014).



METHODS

The goal of this research was to obtain a spatially representative sample of the A.T. tread and its associated infrastructure, including informal trails, day-use recreation sites, and overnight shelters and campsites. Census measurements of the entire tread and associated infrastructure is both unnecessary and would constitute an inefficient expenditure of agency funding. As requested by the sponsor, we applied the Environmental Protection Agency's Generalized Random Tessellation Stratified (GRTS) sample design to sample selected A.T. segments for all field assessments (Brown et al. 2015; Stevens and Olsen 2004). The GRTS sampling algorithms achieve spatial balance between the sampled A.T. trail segments, and within these segments, of trail transects where trail condition measurements were conducted.

Sample Selection

The A.T. was divided into 705 five-kilometer segments and 63 were selected using the GRTS sampling algorithm During three summers of fieldwork (2015-17) field staff carefully searched each segment within 150m of the A.T. centerline by following all informal (visitor-created) trails to locate and assess all disturbed areas judged to have been created by overnight camping, including in the vicinity of shelters.

Team member Dr. Chris Carr, consulting with NPS Inventory and Monitoring Program (I&M) staff, performed the GRTS sampling process. Our sampling decision-making began with a consideration of logistical efficiency from the perspective of accomplishing the necessary fieldwork. Specifically, how long a segment of the A.T. could we reasonably expect to assess in a single day with 2-3 field staff to avoid the necessity of carrying overnight backpacking gear? After consideration we selected an A.T. segment length of 5 km (3.1 mi). The GRTS sampling process generated a list of 75,000 random points that are spatially-distributed along the A.T. centerline from Maine to Georgia. In 2015, our first year of fieldwork, we assessed the New England A.T. section from Katahdin Mountain, ME, to the Connecticut/New York border, a distance of 734 miles (1181 km) that included the first 24,788 GRTS sample points. Given the field schedule and project objectives we decided on a 9% sample of 21 5k segments. A random number generator was used to select a number between 0 and 1, which was multiplied by 24,788 to obtain a start point location in the GRTS list. The next consecutive 20 points were then selected and numbered 1 to 21 in the order of the GRTS listing (Figure 5). We assigned each sample point as the center point of the A.T. 5 km segment, so the segments extended 2.5 km south and north of the sample points.

These procedures were replicated to sample the southern one-third of the A.T. assessed in 2016, from Springer Mountain, GA, to a point due east of Troutville, VA, and the remaining central one-third of the A.T. was sampled and assessed in 2017. Fieldwork was conducted from late May to mid-July each year and a total of 63 5 km segments (196 mi, 315 km) were assessed. Prior to fieldwork, staff prepared supplementary information for field staff from various A.T. guide books, internet searches, and GIS work to list segment access and parking locations, alternative A.T. side-trails, the GPS locations of the segment start and end points, and closest campgrounds. We note that NPS I&M staff with expertise in GRTS sampling advised against stratifying the sampling, recommending the use of post-hoc analyses to examine the influence of regions, plant communities, or other stratifications.

A second stage of GRTS sampling was then conducted for each of the 63 5 km segments to determine the sample locations where A.T. tread conditions were assessed. Within each sampled segment, the GRTS sample point list was again referenced to select the first 50 points, providing a second spatially-balanced representative sample (Figure 6). Field staff navigated to each of these points with a Trimble Geo7X GPS unit and established a temporary trail transect oriented perpendicular to the tread. The distances between these varied but on average they occurred every 328 ft (100 m) and no closer than 26 ft (8 m). A total of 3,150 A.T. trail transects were established and assessed over the three seasons of A.T. fieldwork.

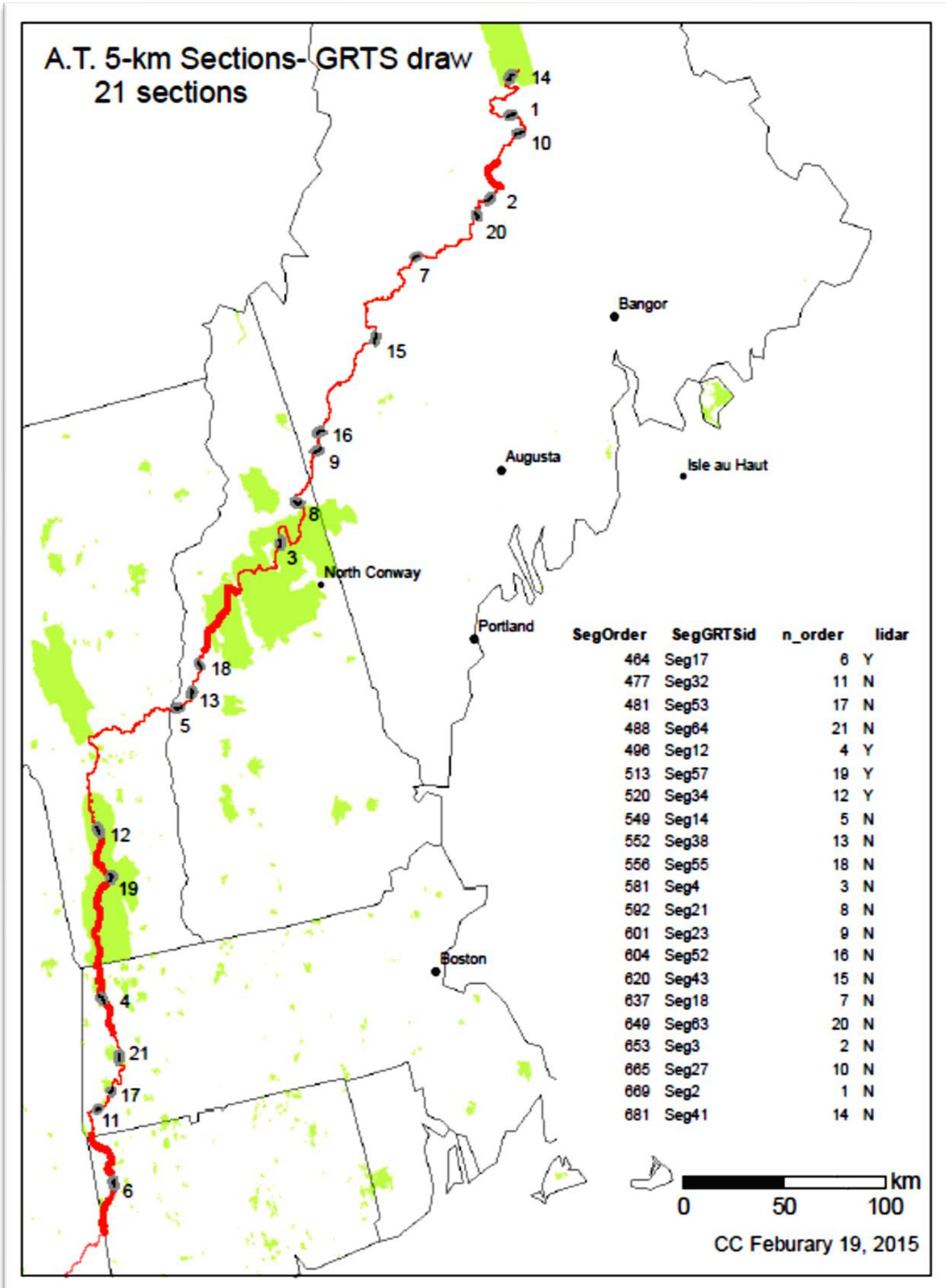


Figure 5. Map showing the locations of 21 5 km sampled segments for the northern one-third of the AT.

According to the NPS I&M staff who assisted us with the GRTS sampling, autocorrelation problems associated with sample points being too close together is "only an issue in terms of very slightly less information from a point only 26 ft away than if that second point had been in the middle of the longest interval elsewhere in the segment; statistically they are an independent random draw from the segment, not autocorrelated or pseudo-replicated" (Stevens and Olsen 2004). Regarding GRTS sampling and autocorrelation concerns, see also Lister and Scott (2009).

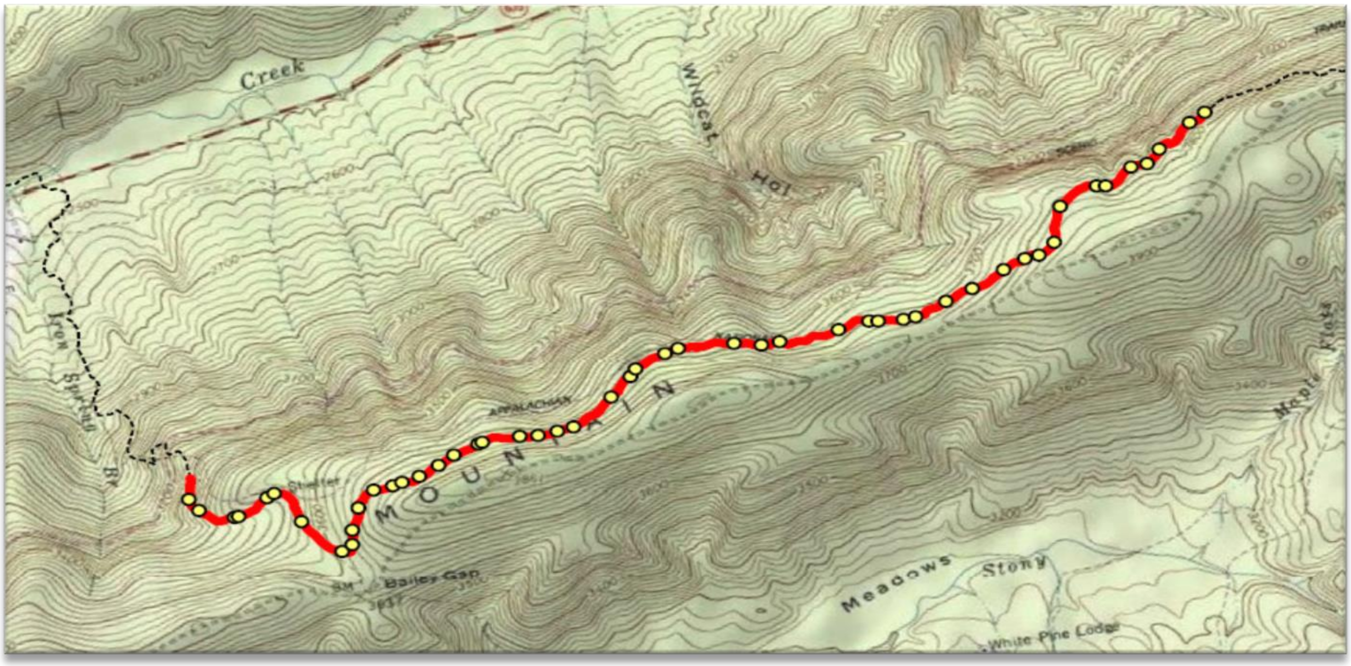
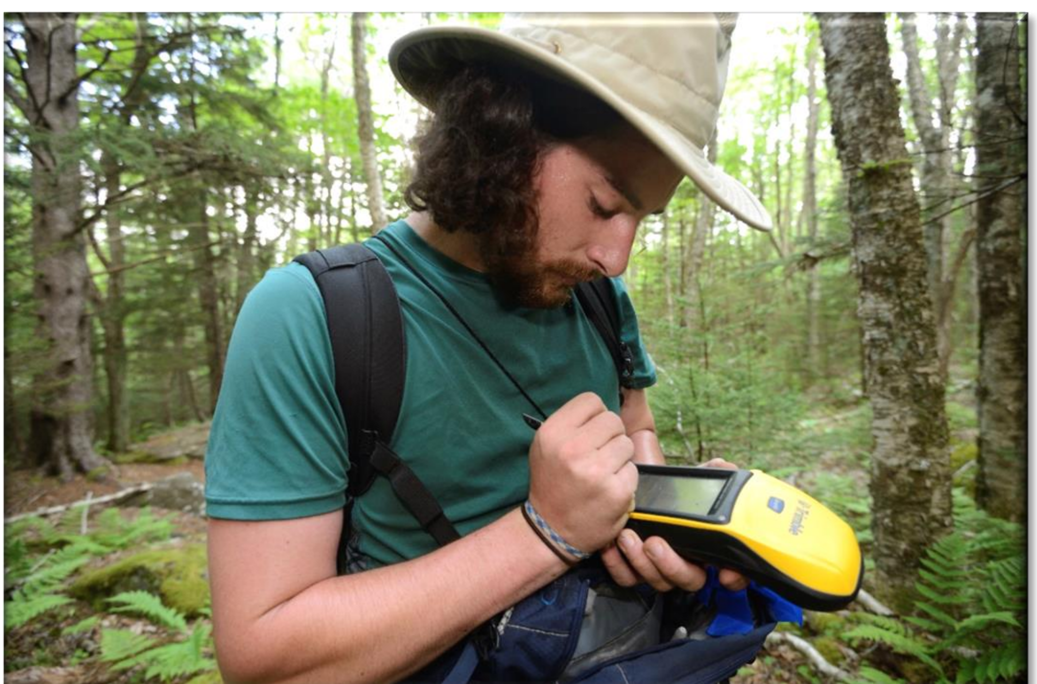


Figure 6. Map showing the locations of 50 sample points determined by second-stage GRTS sampling where AT tread conditions were assessed at temporary trail transects.



Description of Fieldwork

The selection of indicators and development of field methodologies and protocols we employed were based on substantial research in protected natural areas similar to and including the A.T., and have been published in numerous peer-reviewed journals. Protocols and quality assurance practices were developed, field-tested on the A.T., and revised where necessary prior to field staff training and data collection. Field manuals for assessing the A.T. tread, informal (visitor-created) trails, day-use recreation sites (including all nodal areas of visitor impact such as vista sites or resting spots at trail junctions), and overnight camping sites (including all shelters and campsites) are included in Appendix 2. Some protocols were only applied during one of the three field seasons as sub-studies designed to assess special topics (e.g., mudholes or hammock camping impacts). An overview of the assessment methods follows.

Trail Assessments

Field staff navigated to each A.T. segment and the 50 sample points using a Trimble Geo7X or GeoXH GPS unit. At each sample point staff collected a 50-point averaged GPS center point for later GIS spatial analyses and a temporary trail transect was established perpendicular to the trail tread. All data were recorded on tablets using survey forms created in Qualtrics© in 2015 and Fulcrum© in 2016 and 2017. Oblique and overhead photographs were taken of each transect using tablet cameras. Metal stakes were inserted into the ground at the most pronounced outer boundary of visually obvious human disturbance created by trail use. For example, visually pronounced changes in non-woody vegetation height (trampled vs. untrampled), cover, composition, or when vegetation cover is minimal or absent, by disturbance to organic litter. The objective was to define the trail tread that receives the majority (>95%) of traffic, selecting the most visually obvious boundaries that can be most consistently identified. Transect placements were straight-forward in flat terrain or on direct ascent (fall-line) trails (Figure 7a&b) but required greater judgment to determine to post-construction, pre-use tread surface on side-hill constructed trails (Figure 7c&d). The objective was to measure recent visitation-related soil loss as opposed to historic erosion associated with tread/road construction or pre-recreational use historic activities like firefighting or livestock (Figure 7b&d).

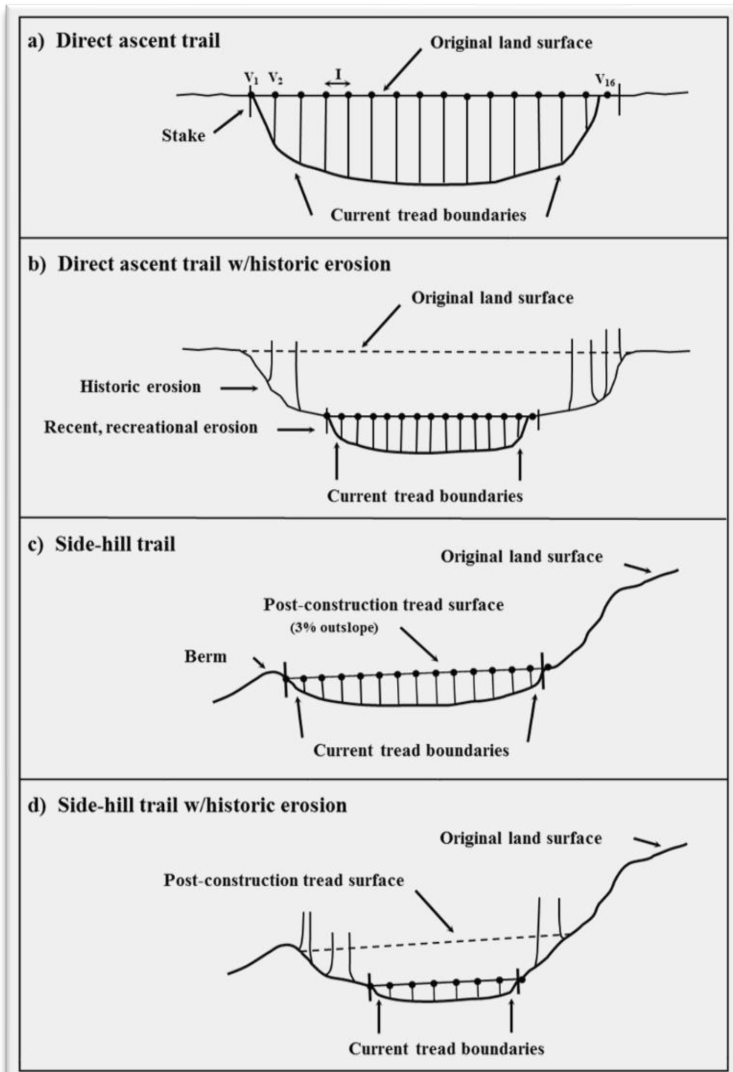


Figure 7. Cross sectional area soil loss was assessed by taking vertical measure every 3.9 in (10 cm) along a tape configured with stakes at tread boundaries to depict the post-construction pre-use tread surface. Diagrams illustrating alternative measurement procedures for direct ascent (fall-line) trail alignments (a & b) vs. side-hill trail alignments (c & d) and for relatively recent erosion (a & c) vs. historic erosion (b & d).

A flexible measuring tape was affixed tautly between the two stakes at a height judged to be the post-construction pre-use tread surface. The distance between the metal stakes was measured as tread width.

Soil loss at each transect was measured using a Cross-Sectional Area (CSA) method (Olive and Marion 2009). Vertical measurements were taken along the horizontal measuring tape every 3.9 in (10 cm) and spreadsheet formulas were developed to calculate CSA based on these data (Figure 7a). Maximum tread incision was measured as the largest perpendicular distance between the transect tape and the tread surface. Soil loss measurements reflect a combination soil compaction, soil displacement, and soil loss from wind and water movement.

Along a 7.9 in (20 cm) band centered on the transect, field staff estimated to the nearest 5% the aggregate proportion occupied by any of the mutually exclusive tread surface categories listed: soil, organic litter, vegetation, rock, mud, gravel, roots, water, wood and other. This procedure provides data that can differentiate lightly impacted trails where tread surfaces are comprised mostly of vegetation cover and organic litter, to heavily-impacted trail segments where tread surfaces are comprised of bare soil, rock, roots, or mud.

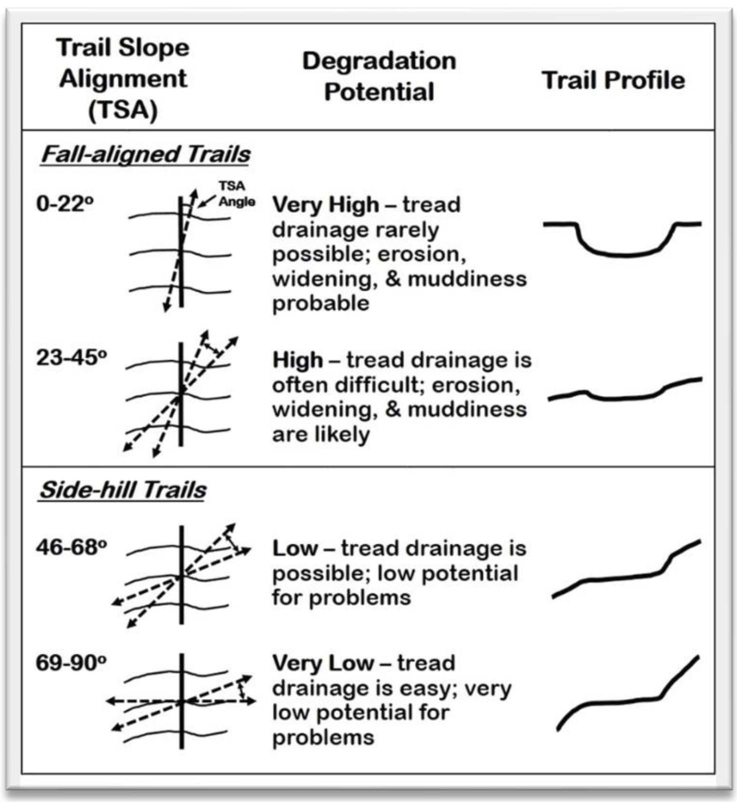


Figure 8. Expected trail degradation potential and trail cross-section profiles for four for four categories of trail slope alignments ranging from fall-line trails (0-22°) to contour-aligned side-hill trails (69-90°). In diagrams above, dashed lines depict trail alignments, solid lines depict the prevailing landform grade or aspect, and curved lines depict contour lines.

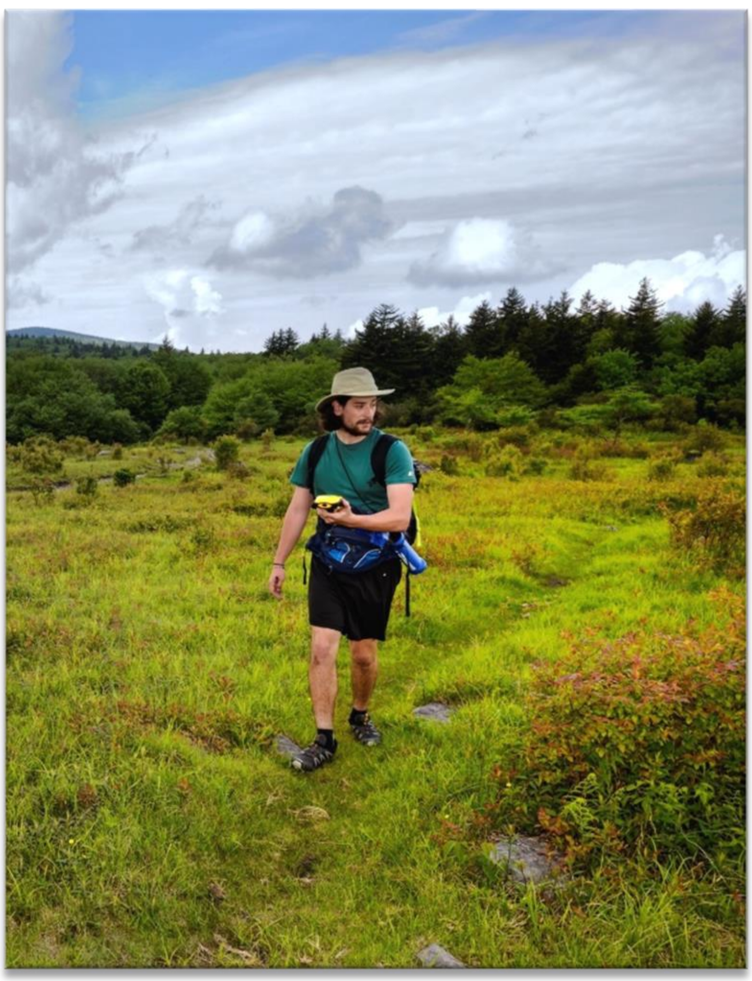
A variety of inventory indicators were assessed to support statistical relational analyses, including trail grade, trail slope alignment angle (Figure 8), and tread construction and maintenance practices. Watershed attributes, vegetation and soil type, and other indicators were also assessed at the site or derived from GIS analyses. Trail grade at the transect was measured to the nearest degree using a clinometer sighted between one field crew member on the transect and another on the trail 3m uphill. Similarly, the landform grade was measured between the transect and a point 9.8 ft (3 m) uphill along the fall-line (the path water would follow if poured on a slope). Trail slope alignment was measured as the smallest difference in compass bearing between the trail and the prevailing landform aspect. Soil texture was determined by feel with a ribbon test at the beginning of each segment and when the survey crew observed changes in soil appearance thereafter (see Appendix 2). Tread type was recorded from the following categories: soil/organic muck, bedrock, rock (cobble to boulder), bog bridge, boardwalk, dirt or gravel road, paved road, rock step/ rock work, sidewalk, and stream.

Special Study: Mudholes

To gather more data to analyze the problem of muddiness, additional transects and special study indicators were applied to purposively assess many of the chronic mud-holes encountered in 2016 and 2017 (southern and central A.T. portions). See Appendix 2, Trail Assessment Manual, for additional special study indicators and guidance.

Informal Trails

All informal (visitor-created) trails (ITs) within 150m of the A.T. centerline were located and walked (see photo below) to record their position with a Trimble GPS unit (see Appendix 2 for field protocols). These corridor boundaries were visible on the GPS unit. IT's are generally created by visitors seeking overlooks, campsites, water sources, or short-cuts. Field procedures were adapted from recent research (Marion et al. 2006, Marion & Carr 2009, Newsome & Davies 2009, Wimpey & Marion 2011). ITs were classified and coded as to their condition class (five descriptive categories) and average width (measured periodically). A data dictionary for the GPS unit was created and used to record all IT data. This work accurately documented baseline conditions for the number, condition, density, and spatial distribution of ITs along the A.T. for future comparison.



Day-Use and Overnight Recreation Site Assessments

Within the 63 study segments field staff located and assessed all day-use recreation sites and overnight shelter and campsites within 492 ft (150 m) of the A.T. centerline, including all A.T. shelters and associated camping areas regardless of distance (Figure 9). Site boundaries and center points were recorded using a Trimble Geo7X or GeoXH GPS and boundary polygons were used to compute site sizes, similar to D'Antonio et al. (2013). Center points were collected as an average of 50 points, while boundaries were collected as polygons formed by walking the edge of each site (Figure 9). Site boundaries were identified by pronounced visually obvious changes in a combination of vegetation cover, vegetation height/disturbance, vegetation composition, and surface organic litter caused from trampling-intensive camping activities (Marion 1995). To mitigate possible accuracy issues of smaller site areas, polygons were visually checked in the field for accurate representations of shape and area on the GPS receiver. Very small sites and/or sites for which accurate GPS readings could not be obtained were measured using the Geometric Figure Method (Marion 1995).

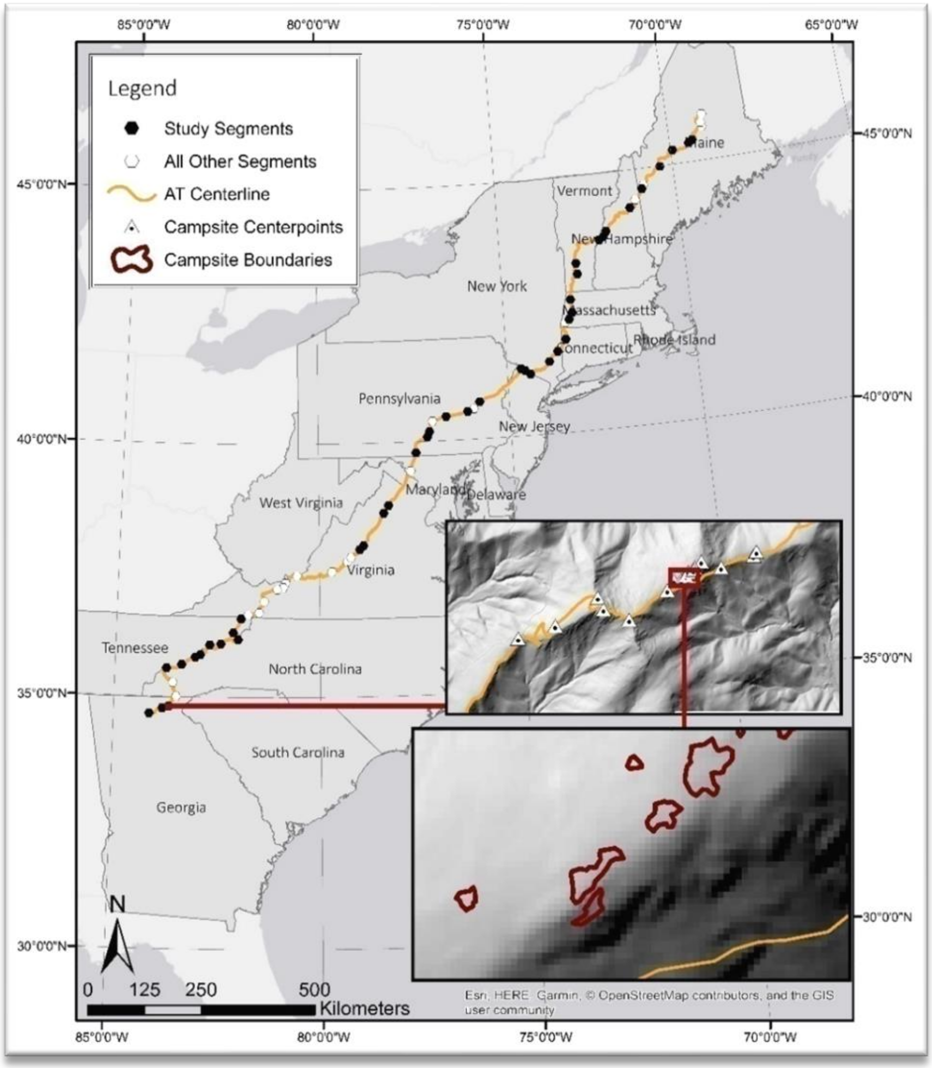


Figure 9. Within each of the sampled 63 sampled segments field staff located and assessed all day-use recreation sites and overnight shelter and campsites. LiDAR data, required for many relational analyses, was available for 42 of the 63 study segments (shown as black hexagons). Insets show some of the campsite locations from segment 3 and an enlarged section revealing individual campsite polygons.

Within each campsite boundary, a percentage estimate of six cover classes (0-5%, 6-25% 26-50%, 51-75%, 76-95%, 96-100%), was recorded for live vegetation groundcover and exposed soil. A percentage estimate of vegetation groundcover was also recorded for an adjacent offsite, environmentally similar control area that lacked human disturbance (Marion 1995). Area of exposed soil was computed by multiplying the midpoint of the cover class for exposed soil by site size. Similarly, estimates of the area over which vegetation loss has occurred were computed by subtracting the midpoint values of onsite vegetation cover from offsite values and multiplying percent vegetation loss by site size.

Other characteristics recorded in the field include estimated use level, campsite type, tree canopy cover, offsite woody vegetation density, offsite topographic roughness, and site expansion potential. Reliable and accurate use data is a perennial problem for recreation site studies in wildland settings (Cole 1986, Cole and Marion 1988, Eagleston and Marion 2017). Visitors do not need to obtain permits to hike or camp along most of the A.T. so there is no practical method for estimating use levels.

Campsite type refers to the following categories: campsite (C), shelter site (S), side-hill campsite (SHC), and campsites on roads (CR) (Figure 10). Side-hill sites are located in sloping terrain and constructed with cut-and-fill excavations to create level campsites with a small expansion-resistant “footprint.” Campsites on roads are those created by visitors or trail managers along former (closed) forest roads. Tree canopy cover was estimated using the six groundcover categories as the percentage of the site shaded by the tree canopy when the sun is directly overhead. Offsite woody vegetation density and offsite topographic roughness (ruggedness due to rocks) were recorded in three categories (low, medium, high), referencing the extent to which vegetation density or landscape roughness in offsite areas would constrain campsite expansion. Site expansion potential was rated using three categories (poor, moderate, high), also referencing the extent to which features in immediate offsite areas would constrain campsite expansion, including slope, rockiness, vegetation density, and/or drainage (Eagleston and Marion 2017).

Figure 10. Photos illustrating four campsite types: C - Campsite, S - Shelter, SHC - Side-Hill Campsite, and CR - Campsite on Road.

Special Study: Hammock Impacts

To investigate the potential resource impacts associated with hammock camping an additional indicator was included in 2016 and applied to all overnight campsites in the southern third of the A.T. Detailed procedures are included in Appendix 2, Recreation Site Assessment Manual and summarized here. Campsites and adjacent off-site areas up to 65 ft were searched for pairs of trees 10-17 ft apart that could have been used by hammock campers. Trunks and limbs within the 4-7 above ground zone were examined on these trees for evidence of hammock-specific camping damage from ropes or webbing. Damage was coded and recording using a 4-class condition rating scale:

Class 1 No visible damage to tree bark that can be attributed to hammock use.

Class 2 Minor damage consisting of a few flaked patches of bark or minor bark compression.

Class 3 Intermediate damage consisting of missing and broken pieces of bark and visually obvious compression of bark.

Class 4 Substantial damage consisting of substantial loss or damage to bark and/or wear and severe compression of bark.

Geospatial Variables

GPS data collected in the field were imported, differentially corrected using Trimble's Pathfinder Office software, and converted to shapefiles for editing in ArcMap 10.5.1 software (ESRI, Redlands, CA, USA). Limited editing was necessary to correct horizontal errors, such as moving the recreation site polygons to the averaged center point. Professional judgement and site photos were used to aid the editing process. When the averaged horizontal error for polygons exceeded 6.5 ft (2 m) the sites were excluded from relational analyses.

A careful search of online data revealed 13 sources of LiDAR-derived Digital Elevation Model (DEM) data that were publicly available, providing coverage for 42 of the 63 sampled A.T. segments (Figure 9). LiDAR data specifications for each source are included in Appendix 1. Four segment DEMs were interpolated from bare-earth classified points using the inverse distance weighting algorithm in the ArcMap software. Obtaining consistent and identical spatial data across the length of the A.T. was not possible due to differing collection sensors, vendors, and processing methods. DEM resolutions included 19 study segments at <1 m, 12 at 1 m, 8 at 2 m, and 3 at 3 m. LiDAR DEM data were considered essential to the relational analyses conducted in this study, which therefore utilized the 42 sampled A.T. segments with LiDAR data.

Relational analyses were conducted to evaluate factors affecting campsite sizes and tread impacts, including soil loss, trail width, and muddiness. The detailed methods for these studies can be found in the referenced journal papers, along with their findings, which are summarized in this report (See Arredondo et al. 2020, Meadema et al. 2020).

A primary goal for managers is to reduce aggregate camping impacts, total areal impact for a defined area. Increases in the aggregate areal extent of camping impacts occur from both the expansion of campsites and the proliferation (creation) of new campsites. To examine management problems with large clusters of campsites and how expansion and proliferation influences aggregate areal impacts on the A.T., we grouped campsites by proximity to each other. To form these clusters, the center point of each campsite was buffered by 100 ft in Arcmap 10.6 using the *Buffer* tool. Any overlapping buffers were then dissolved to form a single polygon around the cluster using the *dissolve* tool (Figure 11).

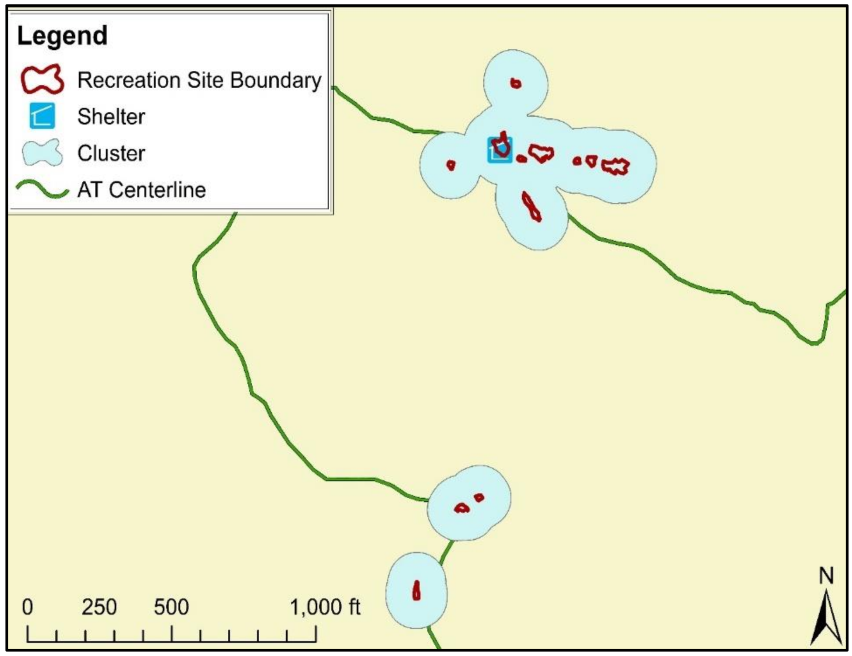
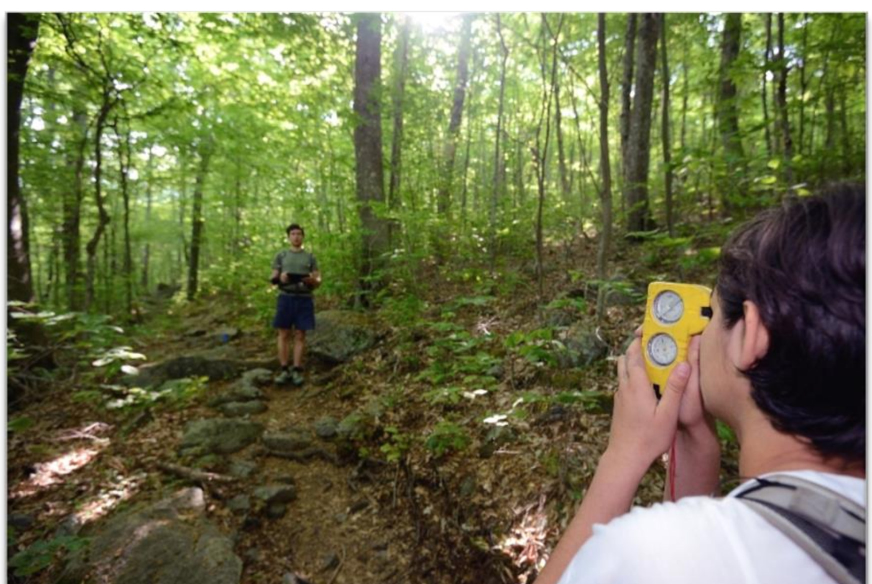


Figure 11. Illustration of the clustering process whereby campsites located within 100 ft of other campsites were clustered together.



RESULTS

Trails

Inventory Indicators

At each transect inventory indicators were recorded to assess characteristics of the A.T. tread, including trail type, surface, and design. These indicators reflect the basic trail layout, composition of the tread surface, and can be used to assess sustainability. Trail layout and the intentional manipulation of tread substrates significantly affect the ability of trails to support traffic and withstand natural processes while remaining in good condition.

Tread Type

At each transect, the dominant tread type was recorded as one of the ten tread types listed in Table 5. More complete definitions for these categories and assessment protocols are included in Appendix 2. The majority (87.9%) of trail transects were comprised of soil, including exposed mineral or organic soils. Across the various trail management regions, this figure ranged from 85.0% in NERO to 93.1% in SORO. Rock was the next most common tread type, at 5.9% of the tread, followed by bedrock with 1.7%. Due to glaciated thin soils and steep trail routes, NERO had the highest incidence of rocky treads, with 3.4% on bedrock and 7.9% on rock. SORO, VARO, and MARO had lower but relatively similar proportions of rocky transects. Bog bridges and boardwalks increased from south to north, representing 0.1% of SORO transects, 0.7% of VARO transects, 1.3% of MARO transects, and 1.9% of NERO transects. An unusually high proportion (5.6%) of MARO transects were on sidewalk due to the random selection of a survey segment that included sidewalks through Duncannon, PA; although not represented in the sample, the trail is also sometimes routed through towns on sidewalks in other management regions (i.e., Hot Springs, NC, Damascus, VA, and Hanover, NH).

Table 5. Number of transects and percent of the A.T. tread for ten types of tread substrate by ATC management region.

TREAD TYPE[1]	SORO		VARO		MARO		NERO		ALL	
	N	%	N	%	N	%	N	%	N	%
Soil	651	93.1	542	90.3	681	85.2	851	85.0	**2725**	**87.9**
Bedrock	4	0.6	1	0.2	12	1.5	34	3.4	**51**	**1.7**
Rock	38	5.4	31	5.2	34	4.3	79	7.9	**182**	**5.9**
Bog Bridge	0	0.0	0	0.0	2	0.3	16	1.6	**18**	**0.6**
Boardwalk	1	0.1	4	0.7	8	1.0	3	0.3	**16**	**0.5**
Woods Road	2	0.3	6	1.0	10	1.3	10	1.0	**28**	**0.9**
Paved Road	0	0.0	5	0.8	4	0.5	3	0.3	**12**	**0.4**
Rockwork	3	0.4	5	0.8	2	0.3	5	0.5	**15**	**0.5**
Sidewalk	0	0.0	5	0.8	45	5.6	0	0.0	**50**	**1.6**
Stream	0	0.0	1	0.2	1	0.1	0	0.0	**2**	**0.1**
All	699	100	600	100	799	100	1001	100	3099	100

1 – All transects included; this indicator was not recorded for one of the segments.

2 – SORO – Georgia, North Carolina, and Tennessee, 2) VARO – Southwest and Central Virginia, 3) MARO – Mid-Atlantic, and 4) NERO – Connecticut, Massachusetts, Vermont, New Hampshire, and Maine.

Tread Cover

The relative amounts of tread surface cover were estimated from directly above and recorded to the nearest 5% along an 8-inch band centered on each transect; categories included soil, organic litter, vegetation, rock, mud, gravel, roots, water, wood and pavement. Note that the uppermost category was recorded so vegetation cover is assessed first, then organic litter not covered by vegetation, then soil or rocks not covered by vegetation or litter. This indicator is very sensitive to trampling intensity; high-use trails generally have substantially less vegetation cover and organic litter than low use trails. The exposed soil category includes all soil types including organic soils, with organic litter as a separate category unless highly pulverized, thin, and patchy. Vegetation includes live plant cover (herbs, grasses, mosses) rooted within tread boundaries. Rock includes bedrock, boulders, rocks, and natural gravel, with human-placed gravel as a separate category. Mud includes seasonally or permanently wet and muddy soils; this category is intended to indicate persistent muddiness that diverts trail users from the tread and not temporary mud from recent rain.

In the entire A.T. dataset, organic litter was the most common tread surface, accounting for 43.9% of the surveyed trail surface area (Table 6). The mean regional amounts of litter increase when comparing regions from south to north, ranging from 30.3% in SORO to 58.2% in NERO. Soil is the next most common tread surface type at 27.7%, with decreasing regional values from south to north. Although influenced by environmental factors like vegetation type and climate, increases in exposed soil relative to litter may indicate differences in amount of traffic. Immediately post construction, most tread surfaces are predominantly soil with some rock. Because the A.T. is predominantly forested, leaf or needle litter covers most of the trail in the fall each year. During the use season, traffic pulverizes and displaces organic litter, exposing soil. Consequently, increases in soil exposure and decreases in litter are likely to indicate increased use of the trail particularly since the last fall and variations of this ratio may indicate differences in use between A.T. regions. However, these interpretations are confounded by the timing of our field measurements relative to passage of the annual thru-hiker bubble of use. Fieldwork occurred in late May to early July each year, so assessments were made mostly after thru-hikers had passed SORO but before thru-hikers had reached NERO.

Table 6. Percent of the A.T. tread for ten categories of tread surface cover by ATC management region (n=3,099[1]).

TREAD COVER	SORO %	VARO %	MARO %	NERO %	ALL %
Soil	51.3	33.5	24.2	11.4	**27.7**
Litter	30.3	37.6	41.8	58.2	**43.9**
Vegetation	1.6	4.4	5.3	3.7	**3.7**
Rock	14.3	19.7	17.4	13.9	**16.0**
Mud	0.1	0.5	0.9	2.3	**1.1**
Gravel	0.4	1.1	2.0	2.1	**1.5**
Roots	1.8	0.7	1.1	4.7	**2.4**
Water	0.0	0.2	0.1	0.6	**0.3**
Wood	0.2	0.7	1.1	2.0	**1.1**
Pavement	0.0	1.7	6.1	0.3	**2.0**

1 – All transects included; this indicator was not recorded for one of the segments.

The next most common tread surface was rock, comprising 16.0% of our sample. Surprisingly, VARO had the highest amount of rock with 19.7% and NERO had the lowest with 13.9%. However, note that NERO, which many would expect to have substantial amounts of rock, also had the most organic litter, which can cover rock. For predominant tread type NERO does have the most rock (Table 5).

Vegetation cover on the A.T. averaged 3.7%, ranging from 1.6% in SORO to 5.3% in MARO (Table 6). Similar to organic litter, vegetation cover is indicative of amount of use, but vegetation cover can be quite common on treads that cross grassy meadows due to the substantially high resistance and resilience (ability to recover) of grasses. Experimental trampling studies reveal that grasses and sedges can tolerate 25 to 30 times as much trampling as the least resistant vegetation types, including ferns and taller broad-leafed herbs (Cole 1993b, Pescott and Stewart 2014).

Roots, generally indicative of soil loss from treads, covered 2.4% of A.T. tread surfaces (Table 6). Root exposure was relatively uncommon in the three southernmost regions, ranging from 0.7% in MARO to 1.8% in SORO. NERO had much higher amounts of exposed roots, 4.7%, indicating more extensive soil loss but also reflective of the thinner soils over rock common in the north. Paved surfaces comprised 2.0% of the A.T., predominantly on sidewalks as hikers walk through towns or across bridges. Human-placed gravel was exposed on 1.5% of all assessed treads and was more common in the northern half of the trail. Gravel is most often encountered when the trail crosses or is briefly routed along a graveled road.

Muddiness, averaging 1.1% of the surveyed tread surface, increased from south to north, ranging from 0.1% in SORO to 2.3% in NERO (Table 6). Wood, which reflects the presence of boardwalks or bog bridging to respond to muddiness, or water bars to mitigate soil loss, was also more common in the north, increasing from 0.2% in SORO to 2.0% in NERO. Finally, standing or running water averaged just 0.3% of treads but ranged from 0.0% in SORO to 0.6% in NERO. A pie chart illustrating the proportions of these tread surface categories is included as Figure 12.

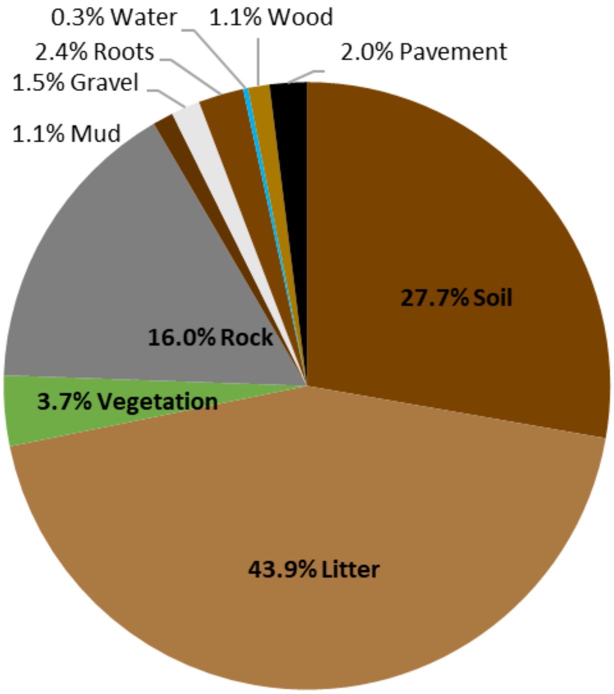


Figure 12. Pie chart illustrating the relative proportions of AT tread surface cover.

Rugosity

Rugosity is a measure of the roughness of trail treads. Trails with smooth surfaces are easier for visitors, and they typically remain narrow because they provide an established easy route for travel. Trails with exposed rocks or roots are more difficult to use, and often become wide as visitors move laterally to seek smooth footing. Two indicators were used to assess rugosity: 1) a visual categorical assessment assigning either smooth, intermediate, or rough to each transect, and 2) a quantitative value calculated as the standard deviation of the vertical CSA measures at each transect, with larger values indicative of rougher trails.

For the entire A.T., a somewhat surprising 77.5% was rated as smooth, 17.9% as intermediate, and only 4.5% as rough (Table 7). Categorical assessments suggest that MARO has the highest occurrence of rougher trail treads, with the highest percentages of intermediate and rough transects. The measured rugosity indicator reveals NERO as having the most rugose A.T. treads and we find this measure to be more reliable. Many of these rough transects were found where the trail passes through extremely rocky areas, for example, in Pennsylvania. Surprisingly, NERO has only slightly higher relative amounts of rough transects than SORO and VARO and has the highest percentage of smooth transects. This is particularly surprising given the large amounts of roots found on trail treads in the NERO region. Interestingly, although MARO has the highest proportion of categorically assessed rough treads

(7.6%), it has the lowest proportion of measured rough (>=1) transects (3.4%). This is potentially due to the influence of more measurements on exceptionally wide and flat roadbeds on standard deviation values.

Table 7. Percentage of the A.T. and ATC management region based on number of transects for two different assessments of tread rugosity (roughness).

RUGOSITY	SORO		VARO		MARO		NERO		ALL	
	N	%	N	%	N	%	N	%	N	%
Smooth	555	79.3	485	80.8	508	63.6	854	85.4	2402	**77.5**
Intermediate	121	17.3	99	16.5	230	28.8	106	10.6	556	**17.9**
Rough	24	3.4	16	2.7	61	7.6	40	4.0	141	**4.5**
Totals:	700	100	600	100	799	100	1000	100	3099[1]	100
MEASURED RUGOSITY (in)										
0 - .49	518	74.9	428	74.0	578	79.0	711	67.7	2235	**73.3**
.5 - .99	131	18.9	118	20.4	129	17.7	220	21.0	598	**19.6**
>=1	43	6.2	32	5.5	25	3.4	119	11.3	219	**7.2**
Totals:	692	100	578	100	732	100	1050	100	3052[2]	100

1 - All transects included. This indicator was not recorded for one segment (n=50).
2 - Transects where soil loss was not recorded are omitted (n=97).

Trail Design: Trail Grade and Slope Alignment Angle

A substantial number of studies, including research on the A.T., demonstrate that steep trails with high grades are more prone to trail degradation, including soil loss and widening (Fox and Bryan 2000, Marion and Wimpey 2017, Meadema et al., 2020, Nepal 2003, Olive and Marion 2009). These studies also reveal that a trail's alignment to the prevailing landform grade is another important factor determining trail sustainability. This report presents data on trail grade and trail slope alignment angle (Figure 8) which are combined to provide a *Trail Sustainability Rating* index described by Marion and Wimpey (2017). Applying guidance derived from published trail research, trail design and maintenance books, and professional judgment, this framework assigns the following four Trail Sustainability Ratings:

Good: Trail grade of 3-10% and TSA of 23-90°
Neutral: Trail grade of 0-2%
Poor: Trail grade of 3-10% & TSA of 0-22°, trail grade of 11-20% and TSA >23°
Very Poor: Trail grade of 11-20% & TSA of 0-22°, trail grade of >20%

Note that while trails with extremely low grades (0-2%) are least likely to experience tread soil loss, they can be susceptible to muddiness and trail widening, the two other core types of trail impact. "Optimal" trail alignments are side-hill constructed but with trail grades in the 3-10% range. Fall-aligned trails are penalized in the remaining two ratings, as are increasing trail grades, both of which increase the potential for soil loss, the most serious and long-term type of trail impact. Fall-aligned trails are also very susceptible to trail widening.

The following data summaries omit data for transects located on roads, sidewalks, boardwalks, bog bridges, streams, and local high points (grade and TSA are not relevant when the trail slopes down from the transect in both trail directions) (n=192 omitted). Also note that median values are referenced when data are not normally distributed – the median is the 50% percentile, the midpoint of a rank-ordered listing of all values. Trail grade for the A.T. tread ranged from 0-75.4% with a median of 8.7% (Table 8); with a greater proportion of the A.T. in the flat (0-2%) category (19.3%), than exceptionally steep (>20%) category (11.4%). TSA ranged from 0-90° with a median of 50°, with the largest portion of transects (29.8%) in the non-sustainable fall-aligned category (0-22°). A majority of the A.T. (54.7%) is side-hill trail with TSA values >45°, however, less than half of these (23%) have optimal grades of 3-10%. Similarly, the median slope ratio value for the A.T. lies at the middle of the scale (0.5). The amount of rock in tread substrates is another important influence on trail sustainability, though regression modeling indicates it is generally less important than grade and slope alignment (Marion and Wimpey 2017). This variable, assessed as tread surface cover, is also included. Percent cover of rock ranged from 0-100 with a median of 0.

Based on the Trail Sustainability Ratings index, 29.1% of A.T. has a highly sustainable "Good" rating, which extrapolates to 637 mi of the A.T. (Table 8). With routine maintenance these segments should be resistant to soil loss, trail widening, and muddiness. The "Neutral" rating accounted for 18.1% of transects (382 mi), which can be susceptible to trail widening and muddiness. Nearly a third of transects (31.8%) received the "Poor" sustainability rating (696 mi), and 21.2% received the "Very Poor" rating (464 mi). Note that a portion of the transects rated "Poor" or "Very Poor" likely occur in steep rocky areas where the soil was originally thin or absent.

Table 8. Trail sustainability ratings the A.T. based on trail grade and slope alignment angle, with trail-wide descriptive data for sustainability indicators.

INDICATORS (n=2957)[1]		TRAIL SLOPE ALIGNMENT ANGLE				
		0-22°	23-45°	46-68°	69-90°	Totals
Trail Grade	0-2%	4.8%	2.5%	3.9%	8.1%	19.3%
	3-10%	10.5%	5.7%	10.0%	13.0%	39.2%
	11-20%	9.5%	4.8%	9.1%	6.9%	30.1%
	>20%	5.0%	2.5%	2.9%	1.0%	11.4%
	Totals	29.8%	15.5%	25.8%	28.9%	100.0%
Grade (%)	Mean = 10.0		Median = 8.7		Range = 0 – 75.4	
TSA (deg)	Mean = 44.2		Median = 50		Range = 0 – 90	
Slope Ratio	Mean = 0.51		Median = 0.50		Range = 0 – 1	
Rock (%)	Mean = 15.6		Median = 0		Range = 0 – 100	

1 - Roads, sidewalks, boardwalks, bog bridges, streams and local high points (n=192) omitted.

Table 9 presents the same data by ATC region. Based on trail grade (>20%, steepest), NERO ranks poorest (19.5%, median=8.7) with the others ranging from MARO (4.8%, median=5.2), VARO (7.7%, median=8.7), to SORO (9.4%, median=8.7). Based on TSA (<23°, fall-aligned), NERO also ranks poorest (39.2%, median=40) with the others ranging from VARO (13.6%, median=65), SORO (22.7, median=64), to MARO (36.4%, median=41). The slope ratio index provides similar findings, with NERO mean/median values closest to 1.0 (fall-aligned) and SORO and VARO having the lowest values (Table 9).

Table 9. Trail sustainability ratings for ATC management regions based on trail grade and trail slope alignment angle.

INDICATORS		**TRAIL SLOPE ALIGNMENT ANGLE**				
SORO (n=677)[1]		0-22°	23-45°	46-68°	69-90°	Totals
Trail Grade	0-2%	2.9	1.0	2.6	7.5	14.0
	3-10%	6.5	2.6	7.9	19.7	36.7
	11-20%	10.5	4.6	11.0	13.7	39.9
	>20%	2.7	1.6	3.3	1.7	9.4
	Totals	22.7	9.8	24.9	42.6	100.0
Grade (%)	Mean = 10.1		Median = 8.7		Range = 0 – 48.8	
TSA (deg)	Mean = 52.9		Median = 64		Range = 0 – 90	
Slope Ratio	Mean = 0.42		Median = 0.34		Range = 0 – 1	
Rock (%)	Mean = 14.2		Median = 5		Range = 0 – 100	
VARO (n=560)[2]		0-22°	23-45°	46-68°	69-90°	Totals
Trail Grade	0-2%	0.7	2.1	3.0	10.1	15.9
	3-10%	4.7	4.2	12.9	20.4	42.2
	11-20%	5.7	5.1	12.7	10.8	34.3
	>20%	2.4	2.1	2.4	0.7	7.7
	Totals	13.6	13.4	31.0	42.0	100.0
Grade (%)	Mean = 9.4		Median = 8.7		Range = 0 – 42.4	
TSA (deg)	Mean = 57.7		Median = 65		Range = 0 – 90	
Slope Ratio	Mean = 0.41		Median = 0.33		Range = 0 – 1	
Rock (%)	Mean = 20.4		Median = 10		Range = 0 – 100	
MARO (n=707)[2]		0-22°	23-45°	46-68°	69-90°	Totals
Trail Grade	0-2%	11.3	4.4	6.6	13.7	36.1
	3-10%	15.1	8.2	7.6	10.0	40.8
	11-20%	7.5	3.7	4.7	2.4	18.3
	>20%	2.5	1.4	0.8	0.1	4.8
	Totals	36.4	17.7	19.8	26.1	100.0
Grade (%)	Mean = 6.5		Median = 5.2		Range = 0 – 75.4	
TSA (deg)	Mean = 40.1		Median = 41		Range = 0 – 90	
Slope Ratio	Mean = 0.48		Median = 0.50		Range = 0 – 1	
Rock (%)	Mean = 18.7		Median = 5		Range = 0 – 100	
NERO (n=1013)[2]		0-22°	23-45°	46-68°	69-90°	Totals
Trail Grade	0-2%	3.8	2.3	3.4	3.5	12.9
	3-10%	13.2	7.0	11.5	6.3	38.0
	11-20%	12.2	5.3	8.8	3.2	29.5
	>20%	9.9	4.1	4.2	1.3	19.5
	Totals	39.2	18.8	27.8	14.2	100.0
Grade (%)	Mean = 12.3		Median = 8.7		Range = 0 – 67.5	
TSA (deg)	Mean = 35.0		Median = 40		Range = 0 – 90	
Slope Ratio	Mean = 0.67		Median = 0.75		Range = 0 – 1	
Rock (%)	Mean = 11.5		Median = 0		Range = 0 – 100	

1 – Transects on roads, sidewalks, boardwalks, bog bridges, streams, and local high points omitted. Omitted transects: SORO (n=23), VARO (n=40), MARO (n=92), NERO (n=37).

When combined into the trail sustainability index ratings, NERO has the largest proportion of “Very Poor” ratings (31.8%), with the others ranging from MARO (12.6%), VARO (13.8%), to SORO (20.4%) (Table 10). For “Poor” and “Very Poor” combined, NERO remains in the poorest category (62.3%), with the others ranging from MARO (39.0%), VARO (47.9%), to SORO (57.0%). The ATC region with the most sustainable trail mileage, as evaluated by these ratings, is VARO (38.4%), followed by SORO (30.9%), MARO (26.3%) and NERO (24.8%). By a substantial margin, MARO has the largest percentage of trail in the “Neutral” category (34.7%), reflecting the flatter terrain in the agricultural areas and along ridgetops that the A.T. traverses in this region (Table 10).

Table 10. Trail sustainability ratings summarized by ATC management region (n=2957).

ATC MANAGEMENT REGION	TRAIL SUSTAINABILITY RATINGS			
	Good	Neutral	Poor	Very Poor
SORO (n=677)	30.9	12.1	36.6	20.4
VARO (n=560)	38.4	13.8	34.1	13.8
MARO (n=707)	26.3	34.7	26.4	12.6
NERO (n=1013)	24.8	12.9	30.5	31.8
ALL (n=2957)[1]	29.1	18.1	31.6	21.2

1 – Transects on roads, sidewalks, boardwalks, bog bridges, streams, and local high points omitted. Omitted transects: SORO (n=23), VARO (n=40), MARO (n=92), NERO (n=37).

Trail grade is limited by maximum landform grades, which also govern the ability to create sustainable side-hill trail alignments in flatter topography. Examining trail grades against landform grade offers some additional insights (Table 11). First, note that only 5.5% of the A.T. mileage is located in flat terrain, defined as 0-2% landform grade, while 46.4% of the A.T. is situated on moderate to steep landform grades over 20%. Note that trail builders prefer 30-50% side-slopes in most soils when possible. Within landform grade categories, the highest trail grade category includes the most fall-aligned trail segments. These data reveal that 11.8% of the A.T. is located on moderate to steep landforms (>20%) and has steep trail grades (>20%); these are the least sustainably designed locations (Table 11). Note that trail grades of more than 15-20% are considered steep but landform grades are not considered steep until above about 50%. An additional 12.3% of the A.T. is situated in 10-20% landform grades with 10-20% trail grades, which are also unsustainable alignments. Both these low sustainability cells (colored red) represent “avoidable” impact if relocations could be implemented to reduce trail grades and avoid fall-line routings.

Another cause for concern is the flatter side-hill trail alignments with grades of 0-2% that occur when steeper landform grades (e.g., >10%) allow trail grades in the more optimal 2-10% range without creating fall-aligned routings (colored yellow) (Table 11). Trail segments with the characteristics of these two cells (6.5% of the A.T.) are susceptible to muddiness when tread drainage is not ensured through constructed drainage features and routine maintenance. While tread muddiness is more frequent when landform *and* trail grades are low (primarily 0-2%, but up to about 5%), contour-aligned trails in steeper landform grades can be sustainable but should be examined when underlain by rock or clay and in settings where tread drainage is inadequate.

Table 11. Percentage of the A.T. based on number of transects for four categories of landform grade and trail grade. Red cells include fall-aligned segments susceptible to soil loss and widening; yellow cells include contour-aligned segments that can be sustainable but may be susceptible to muddiness.

INDICATOR		LANDFORM GRADE (%)				
		0-2	2-10	10-20	>20	Total
TRAIL GRADE (%)	0-2	5.5 (n=168)	6.8 (n=208)	3.3 (n=101)	3.2 (n=99)	19.2 (n=576)
	2-10		14.3 (n=437)	11.3 (n=345)	13.8 (n=421)	39.5 (n=1203)
	10-20			12.3 (n=376)	17.5 (n=533)	29.8 (n=909)
	>20				11.8 (n=361)	11.8 (n=361)
Totals		5.5 (n=168)	21.2 (n=645)	27.0 (n=822)	46.4 (n=1414)	100 (n=3049)[1]

1 – Transects at local tread high points and where grades could not be measured comparably (e.g. paved roads) are omitted (N = 100).

Impact Indicators

Trail condition indicators assess trail resource characteristics, including soil loss, width, and muddiness. Several indicators are used to describe soil loss, including maximum incision, mean trail depth, cross sectional area, and root exposure. These four indicators are all assessed from a transect tape established at the post construction tread surface (See Trail Assessment Manual, Appendix 2).

Maximum Incision

Maximum incision is the simplest and most efficient (rapid) measure of soil loss; it is measured as the largest perpendicular distance between the transect tape and the trail surface. For the entire A.T., maximum incision ranged from 0-33.5 in with a median of just 2 in (Table 12, Figure 13). An estimated 16.2% of the A.T. has tread incision of less than an inch but 18.5% has incision exceeding 4 in. Both NERO and MARO have higher median maximum incision values (2.4 in.), but NERO and SORO have the largest proportions of trail with more than 5 inches of incision (16.3% and 12.7%, respectively). This is likely due to the higher trail grades observed in NERO and SORO. NERO has the lowest median maximum incision value, suggesting that although major soil loss is encountered in this region, there are many transects with very little soil loss. This is most likely reflecting the role of glaciers in removing soil from the mountains, leaving thin soil over bedrock – there simply isn't very much soil to lose. MARO has many flat valley areas with low soil loss potential but it also has many steep sections of severely incised trail. VARO's low incision value may be due to lower trail grades and larger amounts of rock in trail treads.

Table 12. Percentage of the A.T. and ATC management region based on number of transects for six categories of maximum incision soil loss; descriptive statistics also included.

MAXIMUM INCISION SOIL LOSS (in)	SORO		VARO		MARO		NERO		ALL	
	N	%	N	%	N	%	N	%	N	%
0 - 1.0	46	6.6	70	12.2	80	11.1	292	28.8	488	**16.2**
1.1 - 2.0	232	33.5	285	49.7	218	30.2	303	30.0	1039	**34.6**
2.1 - 3.0	179	25.8	120	20.9	240	33.2	54	5.3	593	**19.7**
3.1 - 4.0	105	15.2	53	9.2	100	13.8	73	7.2	331	**11.0**
4.1 - 5.0	43	6.2	25	4.4	45	6.2	126	12.4	239	**8.0**
>5	88	12.7	21	3.7	40	5.5	165	16.3	314	**10.5**
Totals:	693	100	574	100	723	100	1013	100	3004	100
NA:	7		26		76		37		145[1]	
Mean:	3		2.2		2.5		3		2.7	
Median:	2.4		1.8		2.4		1.5		2	
Range:	0-16.3		0-23.6		0-33.5		0-30.8		0-33.5	

1 – Transects at boardwalks, roads, rock steps, sidewalks, and streams and at locations where maximum incision was not recorded (e.g., due to extreme rockiness) are omitted (n=145).

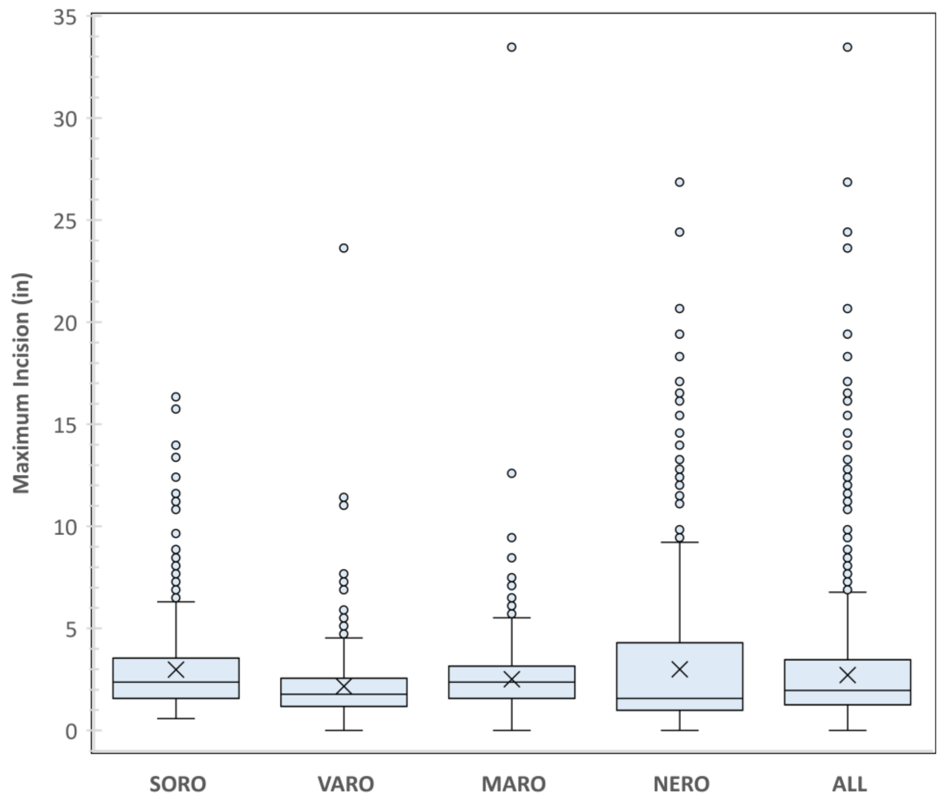


Figure 13. Boxplots illustrating the distribution of values for maximum incision soil loss for the ATC regions.

Boxplot description: A standardized graphical method for displaying the distribution of values. The height of box represents 50% of all values and is defined as the interquartile range (IQR), from the 25th percentile (bottom) to the 75th percentile (top). The median value (50th percentile) is shown with a horizontal line and the mean value is shown with an "x". The horizontal lines above and below the box are located at 1.5 IQR and represent the minimum and maximum values, excluding "outlier" values shown as small circles. If the data are normally-distributed the whiskers are equidistant from the box and the mean and median are close in value, otherwise they illustrate the nature of a skewed distribution. Boxplots are particularly valuable in considering and selecting realistic indicator standards or thresholds, which may differ by management zones.

Cross-Sectional Area Soil Loss

Cross-sectional area soil loss is the sum of the area surveyed between the transect tape and the trail tread. CSA is a more comprehensive and accurate indicator for assessing trail condition and degradation because it reflects soil loss and trail widening, however, it is important to consider the influence of trail width on CSA values. For the entire A.T., CSA has a median value of 32.2 in^2 with a range of 0 to 570.4 in^2 (Table 13, Figure 14). CSA is also a planar areal measurement which can be extrapolated to lengths of trail for volumetric calculations of soil loss. For instance, a foot-long trail segment with consistent incision with a CSA measurement of 36 in^2 has lost 0.25 cubic feet of soil. If we extrapolate the median CSA value of 32.2 in^2 to the 2,190 miles of the A.T., the aggregate soil loss from the entire A.T. is 2,585,660 ft^3 (95,765 yd^3) or 7,980 standard 12 yd^3 dump trucks.

MARO and SORO have the highest median CSA values. SORO's high values may be attributed to high grades, deeper soils, higher precipitation, and high use. MARO's high values may reflect the many wider trails in flat terrain and along old woods roads. Lower VARO values may be due to the lower trail grades and increased amounts of rock in the trail tread. Low median CSA values in NERO given the prevalence of steep fall-aligned trails there are likely attributed to the self-limiting nature of the thin original soils over rock.

Table 13. Percentage of the A.T. and ATC management region based on number of transects for six categories of cross-sectional area soil loss; descriptive statistics also included.

CROSS-SECTIONAL AREA SOIL LOSS (in^2)	SORO		VARO		MARO		NERO		ALL	
	N	%	N	%	N	%	N	%	N	%
0	2	0.3	2	0.3	32	4.4	29	2.9	65	**2.2**
0.1 - 25	170	24.5	230	40.1	138	19.1	554	54.7	1093	**36.4**
25.1 - 50	230	33.2	216	37.6	223	30.8	221	21.8	890	**29.6**
50.1 - 75	129	18.6	56	9.8	144	19.9	86	8.5	415	**13.8**
75.1 - 100	54	7.8	39	6.8	80	11.1	37	3.6	210	**7.0**
>100	108	15.6	31	5.4	106	14.7	86	8.5	331	**11.0**
Totals:	693	100	574	100	723	100	1013	100	3004	100
NA:	7		26		76		37		145[1]	
Mean:	58.4		39.7		59.6		39		48.7	
Median:	42.6		28.3		45.7		21.9		32.2	
Range:	0-424.3		0-546		0-466.6		0-570.4		0-570.4	

1 – Transects at boardwalks, roads, rock steps, sidewalks, and streams and at locations where CSA was not recorded (e.g., due to extreme rockiness) are omitted (n=145).

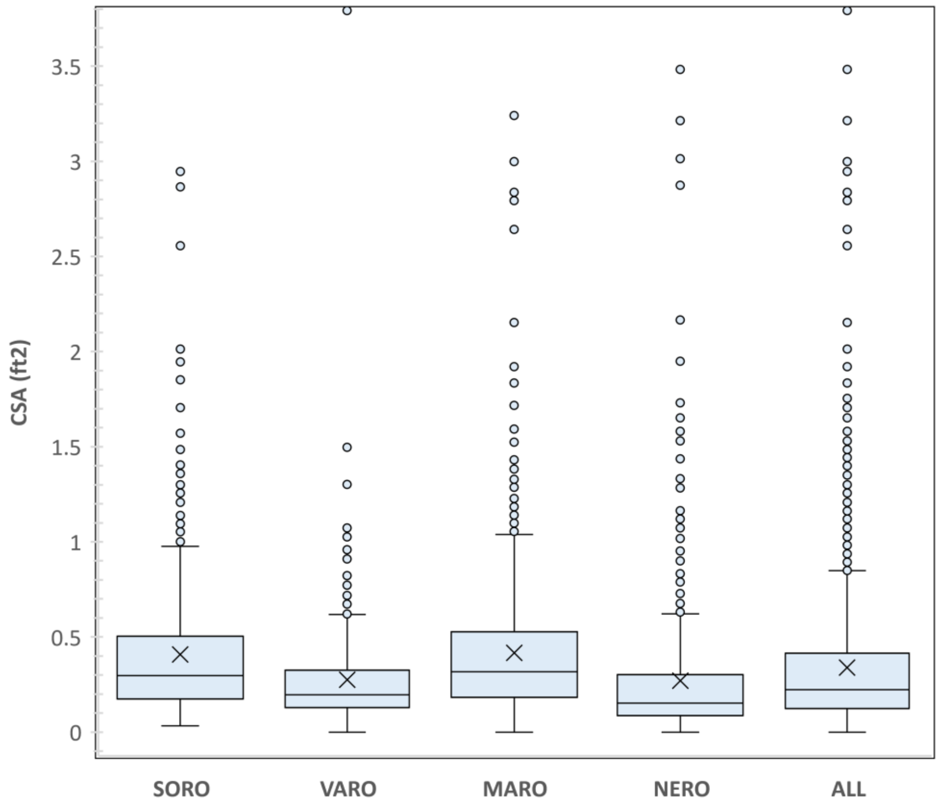


Figure 14. Boxplots illustrating the distribution of values for cross sectional area soil loss for the ATC regions.

Mean Trail Depth

Mean trail depth is the average of all vertical measures between the transect tape and the tread surface. This value reflects soil loss on the trail tread and is influenced by the uniformity and width of transects. Uniformly incised transects have mean depth measurements close to their maximum incision value, whereas transects where traffic is avoiding the primary gully may have lower mean trail depth values due to the inclusion of a newly impacted area which has not yet lost soil. For the entire A.T., trail depth had a median of 1.3 in. with a range of 0 to 15.8 in. (Table 14, Figure 15). Mean trail depth values for the ATC regions roughly corresponded to the other soil loss indicators. The highest median and maximum values (>3 in) are observed in the SORO and MARO regions, while despite its poor alignments, NERO has the lowest median and maximum trail depth values.

Tree Root Exposure

Root exposure within the tread is a less accurate and reliable measure of soil loss due to varying soil depths and tree densities, including the lack of trees in some areas. However, the exposure of tree roots does increase tread rugosity and hiking difficulty and can therefore be a useful indicator. For the entire A.T. root exposure had a median value of 0 (mean=2.5%) with a range of 0 to 97% (Table 15). NERO had the highest mean value (5%) and was the only region with values over 50% (n=8).

Trail Width

The objective of land managers is to minimize the “footprint” of trail impact by keeping trails no wider than necessary to accommodate intended trail use. Adding just one foot to the width of 8.25 miles of trail increases aggregate impact to vegetation and soils by an acre. Trail width was measured between two transect stakes placed at the outer boundaries of visually obvious human disturbance (see Appendix 2, Trail Assessment Manual). Trail width is influenced by tread construction and maintenance, but the concentration of visitor trampling is the primary determinant for well-established trails. Some trail segments are routed along old roadbeds, which more easily allow trails to become wider. Field staff established tread boundaries based on visual trampling disturbance to vegetation, organic litter, and substrates rather than original road-bed boundaries, however, occasionally trampling impacts had altered most of the roadbed. In rare instances, the A.T. is intentionally wide for accessibility or emergency purposes.

For the entire A.T., trail width has a median value of 22.2 in with a range of 0 to 196.9 in (Table 16, Figure 16). Multiplying median width by the A.T.'s length (both in ft) yields an estimated 21,391,920 ft^2 (491 acres) for the total area of intensive A.T. tread disturbance. Just over half of the A.T. (58.6%) is 2 ft or less in width, while 15.2% exceeds 3 ft in width. Median trail widths increase from south to north, ranging from 20.3 in in SORO to 24.6 in in NERO. While only 2.2% of SORO trails are greater than 4 ft wide, 9.5% of MARO's trails and 10.9% of NERO's trails exceed this width. In NERO, wide trails are predominantly degraded fall-line trails and some high use segments through meadows; MARO's widest trails are often coaligned with woods roads. The low trail widths observed in SORO and VARO are most likely due to their frequent side-hill alignments, which are substantially less susceptible to use-related widening.

Table 14. Percentage of the A.T. and ATC management region based on number of transects for eight categories of mean trail depth soil loss; descriptive statistics also included.

MEAN TRAIL DEPTH (in)	SORO		VARO		MARO		NERO		ALL	
	N	%	N	%	N	%	N	%	N	%
0 - 0.5	17	2.8	33	6.6	52	8.0	290	26.9	392	**12.7**
0.51 - 1.0	97	14.1	159	27.5	108	14.8	371	38.1	735	**24.7**
1.01 - 1.5	142	20.4	179	30.9	120	16.5	160	16.1	601	**20.1**
1.51 - 2.0	131	18.8	84	14.5	151	20.7	93	9.3	459	**15.3**
2.01 - 2.5	87	12.5	60	10.4	130	17.9	43	4.2	320	**10.7**
2.51 - 3.0	69	9.9	22	3.8	71	9.8	20	2.1	182	**6.1**
3.01 - 4.0	60	8.6	26	4.5	54	7.3	16	1.6	156	**5.2**
>4.0	90	12.9	11	1.9	37	5.1	20	1.8	156	**5.2**
Totals:	693	100	574	100	723	100	1013	100	3004	100
NA:	7		26		76		37		145[1]	
Mean:	2.4		1.5		1.9		1.0		1.6	
Median:	1.9		1.2		1.8		0.7		1.3	
Range:	0-15.8		0-8.7		0-11.8		0-14.8		0-15.8	

1 – Transects at boardwalks, roads, rock steps, sidewalks, and streams and at locations where soil loss could not be reasonably measured (e.g. due to extreme rockiness) omitted (n=145).

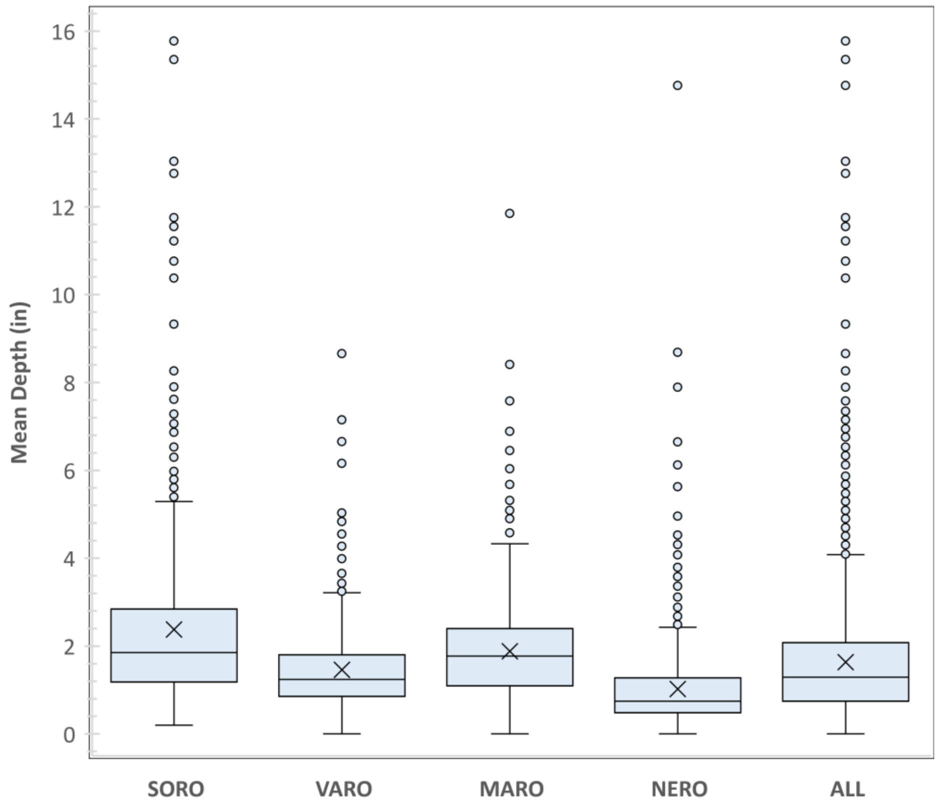


Figure 15. Boxplots illustrating the distribution of values for mean trail depth for the ATC regions.

Table 15. Percentage of the A.T. and ATC management region based on number of transects for four categories of percent tree root exposure on tread transects; descriptive statistics also included.

EXPOSED ROOTS (%)	SORO		VARO		MARO		NERO		ALL	
	N	%	N	%	N	%	N	%	N	%
0-25	683	98.6	571	99.5	722	99.3	942	92.8	2918	**97.0**
30-50	10	1.4	3	0.5	5	0.7	63	6.4	81	**2.7**
55-75	0	0.0	0	0.0	0	0.0	7	0.7	7	**0.2**
80-100	0	0.0	0	0.0	0	0.0	1	0.1	1	**0.0**
Totals:	693	100	574	100	727	100	1013	100	3007	100
NA:	7		26		72		37		142[1]	
Mean:	1.9		0.8		1.2		5		2.5	
Median:	0		0		0		0		0	
Range:	0-50		0-40		0-45		0-97		0-97	

1 - Transects at roads, sidewalks, boardwalks, bog bridges, and streams omitted (n=142).

Table 16. Percentage of the A.T. and ATC management region based on number of transects for seven categories of trail width at tread transects; descriptive statistics also included.

TRAIL WIDTH (in)	SORO		VARO		MARO		NERO		ALL	
	N	%	N	%	N	%	N	%	N	%
0-12	11	1.6	5	0.9	24	3.3	9	0.9	49	**1.6**
12.1-18	202	29.2	170	29.6	133	18.4	162	16.0	667	**22.2**
18.1-24	306	44.3	222	38.7	215	29.7	303	29.9	1046	**34.8**
24.1-30	102	14.8	100	17.4	129	17.8	218	21.5	549	**18.3**
30.1-36	29	4.2	28	4.9	70	9.7	108	10.7	235	**7.8**
36.1-48	26	3.8	29	5.1	84	11.6	103	10.2	242	**8.1**
>48	15	2.2	20	3.5	69	9.5	110	10.9	214	**7.1**
Totals:	691	100	574	100	724	100	1013	100	3002	100
NA:	9		26		75		37		147[1]	
Mean:	22.1		23.3		27.8		30.1		26.4	
Median:	20.3		20.9		23.6		24.6		22.2	
Range:	9.8 - 104.9		10.2 - 76.0		0 -120.5		5.2 – 196.9		0 - 196.9	

1 - Transects at roads, sidewalks, boardwalks, bog bridges, streams and at locations where a tread width was not recorded omitted (n=147).

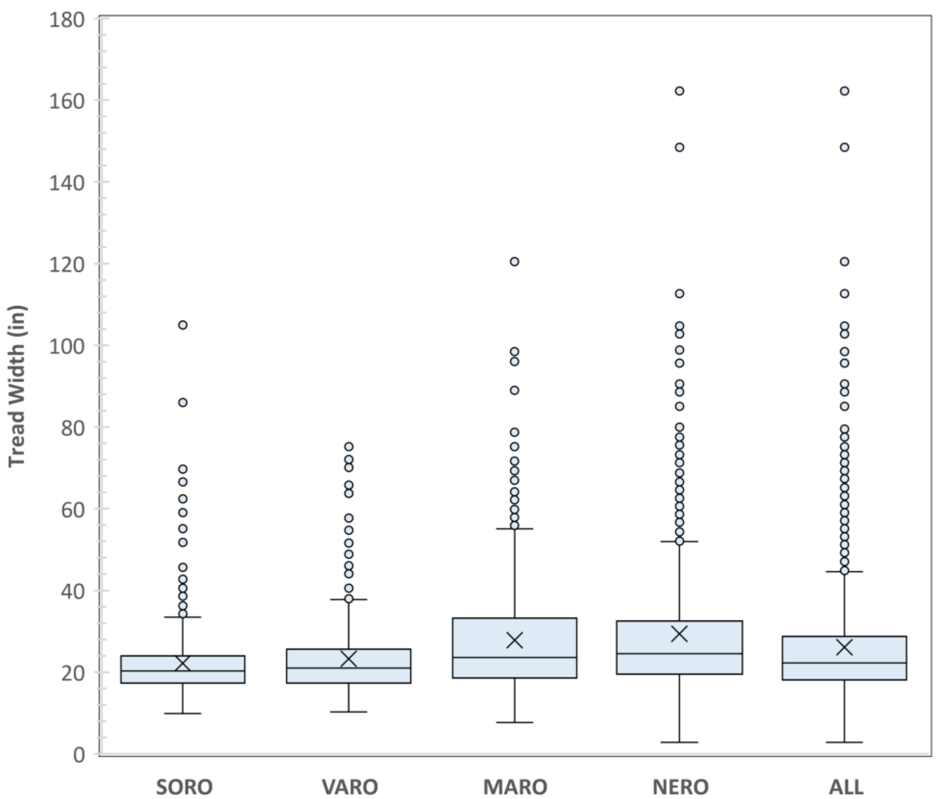


Figure 16. Boxplots illustrating the distribution of values for trail width for the ATC regions.

Tread Muddiness

Muddiness on trails is avoided by hikers, who either widen trails or create secondary circumventing informal trails. Trail muddiness can occur from treads intercepting and retaining water from rainfall, snowmelt, or persistent seeps and springs. In flatter terrain, incised trails capture water that can't easily be drained except downslope on the trail. In sloping terrain, incised side-hill trails capture water that may not be easily drained due to substantial soil loss or the development of lower-side berms. Drainage issues may be challenging and pervasive in flat terrain or may be caused by insufficient, ineffective, or unmaintained tread drainage features in flat and sloping terrain.

For the entire A.T., muddiness assessed on transects had a median value of 0 with a range of 0-100% (Table 17). As in most trail studies, muddiness is an uncommon problem and for the A.T. only 1.7% of the transects had more than 25% mud cover. Mud was much more prevalent in NERO, which had 39 transects with mud covering >30%, compared to 1 in SORO, 3 in VARO, and 10 in MARO. Field observations suggest that NERO has muddiness both in flatter terrain and along relatively level sections of side-hill trail where tread incision and trailside berms have developed. Additional analyses focused on muddiness are included in a later report section.

Table 17. Percentage of the A.T. and ATC management region based on number of transects for four categories of percent mud on tread transects; descriptive statistics also included.

MUD (%)	**SORO**		**VARO**		**MARO**		**NERO**		**ALL**	
	N	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**
0-25	699	99.9	587	99.5	740	98.7	1008	96.3	3034	**98.3**
26-50	0	0.0	0	0.0	3	0.4	22	2.1	25	**0.8**
51-75	0	0.0	1	0.2	2	0.3	10	1.0	13	**0.4**
76-100	1	0.1	2	0.3	5	0.7	7	0.7	15	**0.5**
Totals:	700	100	590	100	750	100	1047	100	3087	100
NA:	0		10		49		3		62[1]	
Mean:	0.1		0.5		0.9		2.3		1.1	
Median:	0		0		0		0		0	
Range:	0-85		0-95		0-95		0-100		0-100	

1 - Paved roads and sidewalks omitted (n=62).

Secondary Treads

Secondary treads parallel to the A.T. at transects but separated by a strip of largely undisturbed vegetation were counted. Visitors create secondary trails when the formal tread becomes excessively muddy or eroded. For the entire A.T., field staff found 110 secondary treads, with 96.5% of transects having no secondary treads, 3% with 1, .3% with 2, and .1% with 3 (Table 18). Secondary treads increased from south to north, including 7 in SORO, 8 in VARO, 30 in MARO, and 65 in NERO. These figures roughly mirror the regional distribution of muddy transects, and along with field observations suggest that mud is a primary driver of the creation of secondary treads on the A.T.

Table 18. Percentage of the A.T. and ATC management region based on number of transects for four categories of secondary treads.

SECONDARY TREADS (#)	SORO		VARO		MARO		NERO		ALL	
	N	%	N	%	N	%	N	%	N	%
0	693	99.0	592	98.7	769	96.3	985	93.8	3039	**96.5**
1	7	1.0	8	1.3	28	3.5	53	5.0	96	**3.0**
2	0	0.0	0	0.0	1	0.1	10	1.0	11	**0.3**
3	0	0.0	0	0.0	1	0.1	2	0.2	3	**0.1**
Totals:	700	100	600	100	799	100	1051	100	3149[1]	100

1 - All transects included.

Modeling Trail Soil Loss

Some relational analyses were conducted to evaluate the influence of various factors on trail soil loss. One-way ANOVA testing confirmed that the severity of soil loss as measured by maximum trail incision varies significantly with trail grade (F = 21.3, p < .0001, df = 3), with a post-hoc Student's *t*-test revealing significant increases between each category of trail grade (Figure 17). A one-way ANOVA test examining the combined influence of trail and landform grade on mean maximum incision found significant differences between groups (F=8.1, p<.0001, df=9), and a post-hoc Student's *t*-test identified the greatest soil loss occurring on transects with trail and landform grades in excess of 20% (Table 19).

Two-way ANOVA revealed that soil loss values vary significantly with both landform grade (F = 24.8, p < .0001, df = 2) and TSA (F = 8.0, p < .0001, df = 4), with a significant interaction between the two (F = 2.3, p = .0169, df =8). In sloping terrain above 10%, maximum incision values increase as TSA values decrease (Figure 18), with the greatest incision values occurring on fall-line trails with landform grades exceeding 20%.

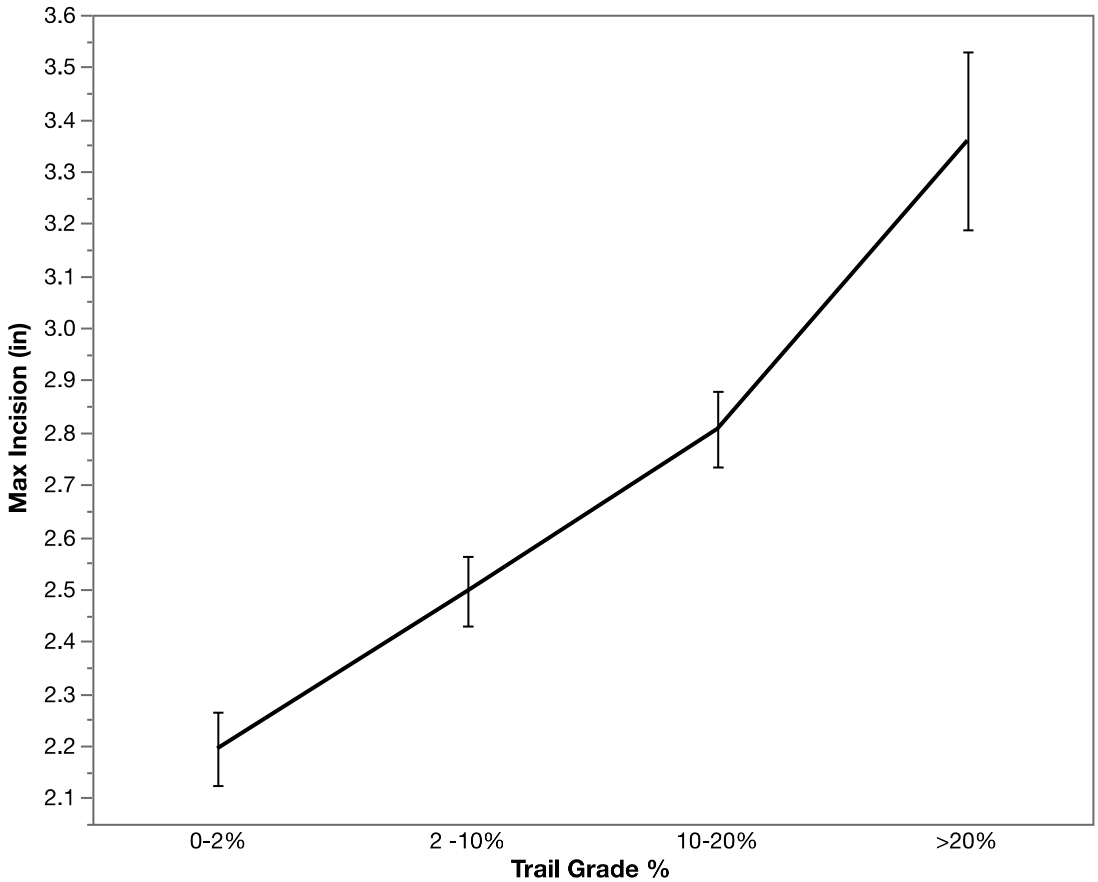


Figure 17. Mean maximum tread incision values are significantly different across trail grade categories. Soil loss increases with increasing trail grade. Error bars represent one standard error from the mean.

Table 19. Mean maximum tread incision values (in) increase with both trail grade and landform grade. The most incised trails are fall-line trails with high trail grades in steep terrain.

TRAIL	LANDFORM GRADE (%)[1]			
GRADE (%)	**0-2**	**2-10**	**10-20**	**>20**
0-2	2.0 E	2.3 DE	2.4 BCDE	2.0 E
2-10		2.3 DE	2.6 CD	2.6 CD
10-20			2.9 B	2.7 BC
>20				3.4 A

1 - Students T Test Groups (ABCDE): Values with the same letter are not significantly different.

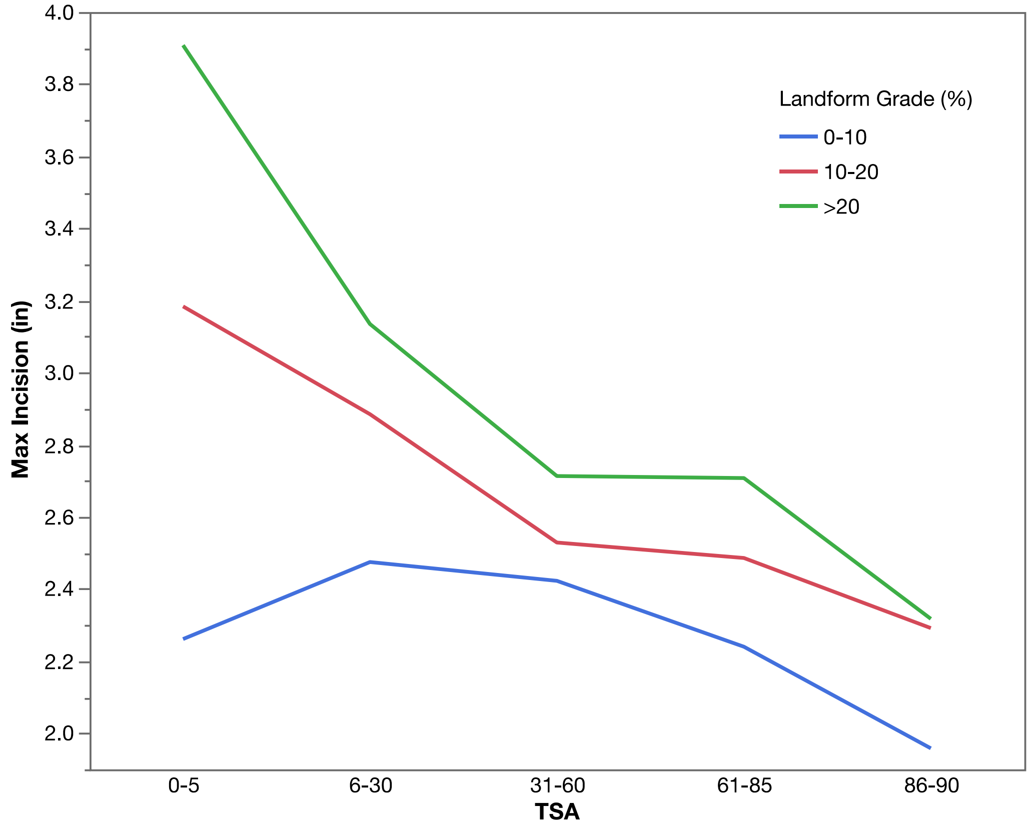


Figure 18. Mean maximum incision values are significantly higher in lower TSA categories, and this relationship is stronger in steeper terrain.

Modeling Trail Muddiness

Muddiness is generally a rare form of trail impact, but even rare problems are substantial on a trail that is 2,190 mi long. In the A.T. sample there were 70 transects (2.2% of the A.T., 48 mi) with mud or standing water assessed as 20% or more of the transect. The sample also included an additional 34 muddy locations (1.1% of the A.T., 24.1 mi) where trail maintainers had installed bog bridging (18 transects) and boardwalks (16 transects). To gather more data to analyze the problem of muddiness, an additional 40 muddy locations were purposively selected and assessed in 2016 and 2017 (southern and central A.T. portions) using the same field procedures.

The distribution of muddy transects by ATC region is presented in Table 20, revealing an increasing prevalence of muddiness from south to north for muddy transects and boardwalks. Combining these two reveals that tread muddiness ranges from a low of 0.3% in SORO to a high of 7.0% in NERO. A finer representation of the distribution is provided in Table 21, though some states were only sampled by one to several of the 63 segments (50 transects/segment) so data likely do not accurately represent some of the states. Regardless, these data reveal Vermont to have the muddiest treads (13.0%), followed by Maine (7.5%), and New Hampshire (7.2); the least muddy A.T. treads were found in Georgia, Maryland, and Connecticut (0.0%) and North Carolina and Tennessee (0.4%).

Table 20. Number and percent of muddy transects (>20% mud) by ATC region.

ATC REGION	MUDDY TRANSECTS		BOARDWALKS		MUDDY + BOARDWALKS		TOTAL TRANSECTS
	N	%	N	%	N	%	N
SORO	1	0.1	1	0.1	2	0.3	700
VARO	3	0.4	4	0.6	7	1.0	699
MARO	11	1.6	9	1.3	20	2.9	700
NERO	55	5.2	19	1.8	74	7.0	1050
ALL	70	2.2	33	1.0	103	3.3	3149

Table 21. Number and percent of muddy transects, boardwalks, and combined measures by state.

STATE	MUDDY TRANSECTS		BOARDWALKS		MUDDY + BOARDWALKS		TOTAL TRANSECTS[1]
	N	%	N	%	N	%	N
GA	0	0.0	0	0.0	0	0.0	150
NC/TN	1	0.2	1	0.2	2	0.4	550
VA	3	0.4	4	0.6	7	1.0	699
MD	0	0.0	0	0.0	0	0.0	50
PA	9	2.3	1	0.3	10	2.5	400
NJ	2	1.3	7	4.6	11	6.0	150
NY	0	0.0	1	1.0	1	1.0	100
CT	0	0.0	0	0.0	0	0.0	50
MA	4	2.0	5	2.5	9	4.5	200
VT	8	8.0	5	5.0	13	13.0	100
NH	15	6.0	3	1.2	18	7.2	250
ME	28	6.2	6	1.3	34	7.5	450
All	**70**	**2.2**	**33**	**1.0**	**103**	**3.3**	3149

1 – Sample sizes may be too low to accurately represent differences between states.

To understand where tread muddiness problems occur the locations where muddiness was found, including data for randomly and purposively selected transects, and transects on boardwalks, are identified by three categories of trail and landform grade in Table 22. While one might expect most muddy trail problems to only occur in relatively flat terrain our data reveal that this is true only for boardwalks, 69.7 of which were constructed in areas of 0-5% trail and landform grade. For the randomly and purposively selected muddy transects only 7.3% were in flat terrain, compared to 10.1% in flat terrain for the entire dataset (Table 22). This suggests that trail maintainers have already placed boardwalks in most areas where they are needed to correct muddiness along A.T. segments that traverse flat terrain with wet soils. A third (33.6%) of the transects within trail grades of 0-5% (colored yellow in the table) are contour-aligned side-hill trails with landform slopes in excess of 5% that have inadequate drainage, generally due to treads that are incised or have berms on the lower trailside preventing water from draining downhill. This is a surprisingly high percentage as drainage excavations should easily resolve the muddiness. For the randomly and purposively selected muddy transects, 23.6% are in locations with 5-10% trail grade and 34.5% are in areas with trail grades above 10%. Examination of photos for these groups revealed that some locations were small flat muddy spots situated within steeper terrain while others were muddy soils on steeper slopes caused by the trail intercepting seeps or spring water.

Table 22. Locations of randomly and purposively selected muddy locations and boardwalks by trail grade and landform grade categories compared to the entire dataset.

CATEGORY	TRAIL GRADE (%)	LANDFORM GRADE (%)			
		0-5	**5-10**	**>10**	**Total**
Entire Dataset (n=3091)[1]	0-5	**10.1**[2] 313	**8.3** 258	**13.2** 407	**31.6** 978
	5-10		**8.3** 258	**19.3** 596	**27.6** 854
	>10			**40.7** 1259	**40.7** 1259
	Total	**10.1** 313	**16.7** 516	**73.2** 2262	**100** 3091
		0-5	5-10	>10	Total
Randomly Selected Muddy + Purposive (n=110)	0-5	**7.3** 8	**12.7** 14	**20.9** 23	**40.9** 45
	5-10		**10.0** 11	**14.5** 16	**23.6** 27
	>10			**34.5** 38	**34.5** 38
	Total	**7.3** 8	**22.7** 25	**70.0** 77	**100** 110
		0-5	5-10	>10	Total
Boardwalks (n=33)	0-5	**69.7** 23	**12.1** 4	**12.1** 4	**93.9** 31
	5-10		**3.0** 1	**3.0** 1	**6.1** 2
	>10			0 0	0 0
	Total	**69.7** 23	**15.2** 5	**25.3** 5	**100** 33

1 - Transects at local high points and locations where a grade was not recorded are omitted (n=58).
2 – Values are percent and N.

Modeling Trail Widening

Two-way ANOVA testing revealed significant differences (F = 8.8, p = .003, df = 1) between mean trail width values within two landform grade categories (Figure 19), but not between different TSA categories (F = 1.9, p = .106, df = 4). However, the interaction effect between TSA and landform grade was significant (F = 3.7, p = .0056, df = 4). As expected, TSA values have little influence on tread width values in flatter terrain (<15%) but have a strong inverse relationship with tread width on slopes above 15%. A one-way ANOVA test comparing mean tread width within combined trail and landform grade categories (Table 23) found significant differences between categories

(F = 3.9, p < .0001, df = 9). Steep, fall-line trails with landform and trail grades exceeding 20% are the widest trails due to erosion-induced roughness. Another one-way ANOVA test found significant tread width differences across three visually-assessed tread rugosity categories (F = 87.3, p < .0001, df = 2). Trails with rough treads from rocks and roots were significantly wider than trails with smooth treads (Figure 20). Finally, average tread width in the random sample is 24.2 in (n = 2,639) while the average tread width for random and purposively surveyed muddy transects is 54.2 in, identifying muddiness as a causal factor for trail widening.

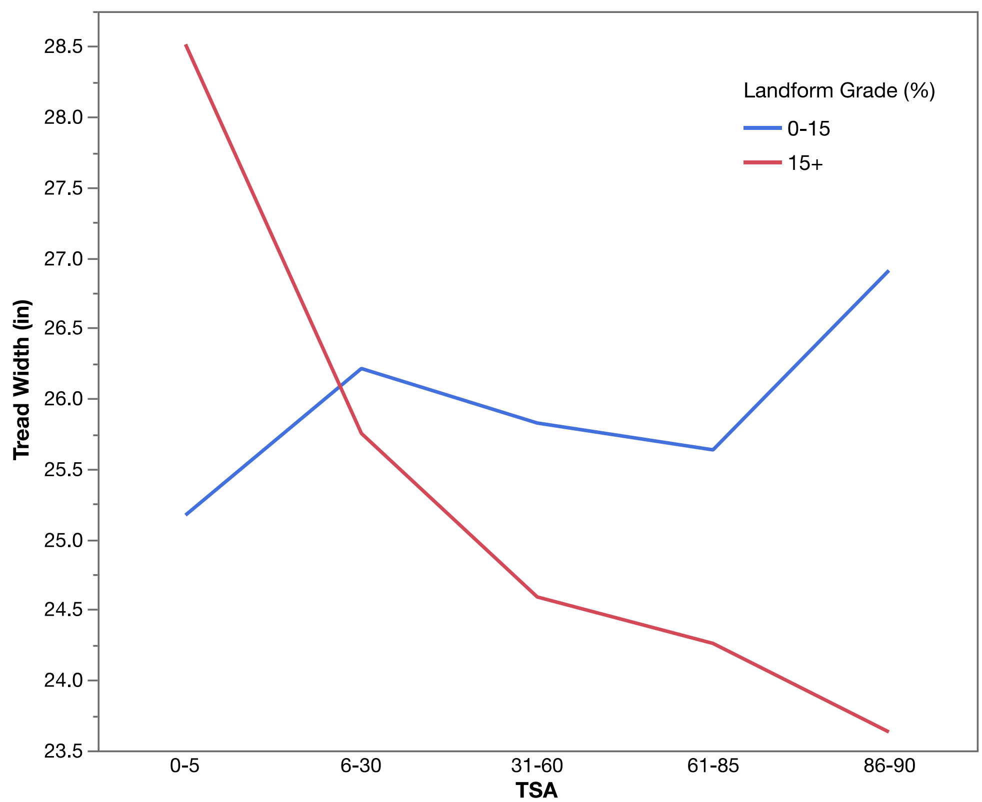


Figure 19. Mean tread width values for different layout categories. In flat terrain, TSA has little bearing on trail width. In sloping terrain, side-hill trails are narrow and fall-line trails become extremely wide. Error bars represent one standard error from the mean.

Table 23. Mean tread width values within different trail and landform grade categories are significantly different.

TRAIL GRADE (%)	LANDFORM GRADE (%)[1] 0-2	2-10	10-20	20+
0-2	62.0 BCD	64.5 ABC	66.2 ABC	66.2 ABC
2-10		67.8 AB	62.6 CD	58.1 D
10-20			65.8 ABC	61.9 CD
20+				69.8 A

1 - Students T Test Groups (ABCDE): Values with the same letter are not significantly different.

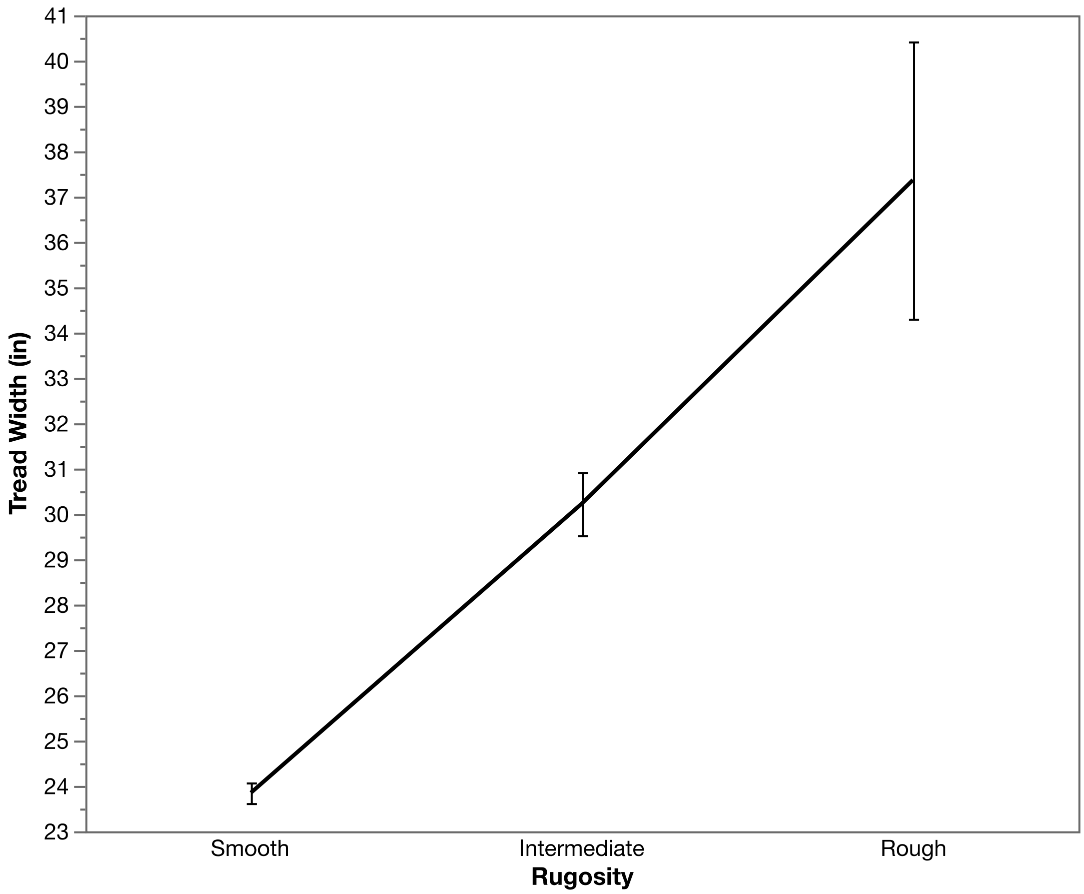


Figure 20. Mean tread width values for different levels of visually-assessed tread rugosity. Treads become rougher when soil loss exposes rocks and roots. Rougher treads become wide because hikers often move laterally to find smoother footing. Error bars represent one standard error from the mean.

Informal Trails

Hikers seeking overlooks, campsites, water sources, or short-cuts often create informal trails (ITs). The proliferation of ITs impact vegetation and soils, potentially including rare and sensitive plant communities. Because IT networks receive no environmental reviews and are not professionally planned, constructed, or maintained they are often less sustainable, can cause severe environmental degradation, and may be less safe and easy for visitors to use (Wimpey & Marion 2011). The excessive proliferation and degradation of informal trails threatens natural resource protection, visitor safety, and the quality of recreation experiences.

Informal trails were surveyed and assessed within a 150-meter-wide corridor centered on the A.T.; field staff searched along all formal trails, campsites, and features of interest. Once an informal trail was located, it was mapped using a Trimble GPS to record its location, length, condition class, and width. Averaged GPS control points were recorded at junctions between formal and informal trails to improve positional accuracy during editing.

Informal Trail Conditions

The number (N) of informal trails is not a preferred indicator because it is influenced by the need to split informal trails into separate segments during survey work. The total length of informal trails or portions in various condition or trail width classes are preferred indicators because they are not influenced by survey methods. The aggregate area of informal trails, calculated by multiplying IT length by average width, is perhaps the most descriptive and managerially relevant indicator.

From our total 9% sample of 195.3 A.T. trail miles, 120,174 linear feet (22.8 miles) of IT's were located and assessed, with a total areal extent of 172,350 ft^2 (3.95 acres). If we extrapolate these findings to the entire 2,190 miles of the A.T., there are an estimated 255 miles of ITs within the A.T. corridor, with an areal footprint of about 1,932,649 ft^2 (44.4 acres).

The number of A.T. segments evaluated in this study varies between management regions, skewing comparisons of aggregate impact between region. For example, 21 segments were surveyed in NERO compared to 12 in SORO. When comparing IT impacts between the two regions it's inappropriate to compare IT total lengths or areal extents due to the much larger area surveyed in NERO. We sought to address this problem by including only mean indicator values in Table 24.

Table 24. Descriptive statistics for width, length, and area of informal trails by ATC management region.

ATC Region	Segments Surveyed	Mean IT Width (in)	Mean Total Length (ft) / Segment	Mean Total Area (ft^2) / Segment
SORO	12	15.6	3,813	5,460
VARO	14	14.2	1,597	1,732
MARO	16	16.0	2,186	3,109
NERO	21	21.7	631	1,208
All	63	**16.0**	**1,938**	**2,738**

For the entire A.T., ITs averaged 16.0 inches in width (Table 24). On a sampled A.T. segment basis, the mean total length/segment was 1,908 ft and the mean total area/segment was 2,736 ft^2. Mean IT average width varied from 14.2 in VARO to 21.7 in NERO. While width is often correlated with amount of use, fall-aligned ITs are generally much wider than side-hill alignments, and ITs that circumvent mud-holes, which are most prevalent in NERO, are wider than other types of ITs. The two segment-based indicators are more managerially relevant as they provide comparable aggregate measures of IT proliferation and impact. The mean total length of ITs per segment show that SORO has more than twice the linear and areal extent of ITs than the other regions (Table 24, Figure 21). Based on aggregate areal impact, NERO and VARO have the least IT impact (1,208 and 1,485 ft^2), MARO with intermediate impact (3,109 ft^2) and SORO at a very high level (6,370 ft^2) (Table 24, Figure 22). Much of the IT development in SORO is associated with its high use levels, including substantial day use in some areas. While NERO also has high use in places like the White Mountains, much of that use is in rocky subalpine settings with insufficient soils and vegetation for ITs to develop, or in areas with nearly impenetrable spruce-fir forests that constrain off-trail travel.

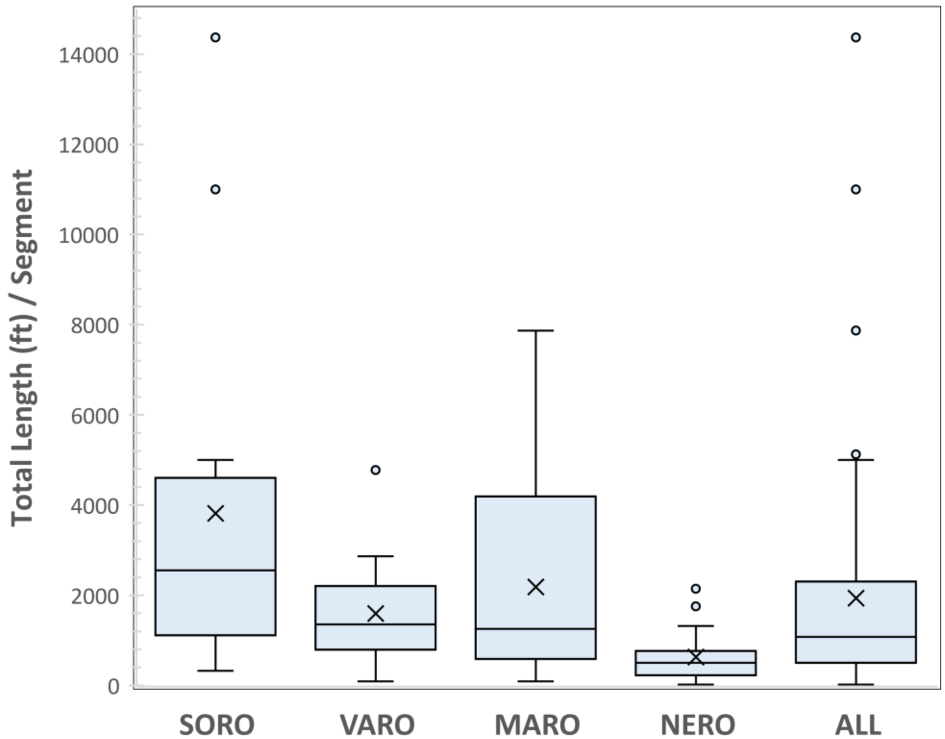


Figure 21. Boxplots illustrating the distribution of values for total length of informal trails for the ATC regions.

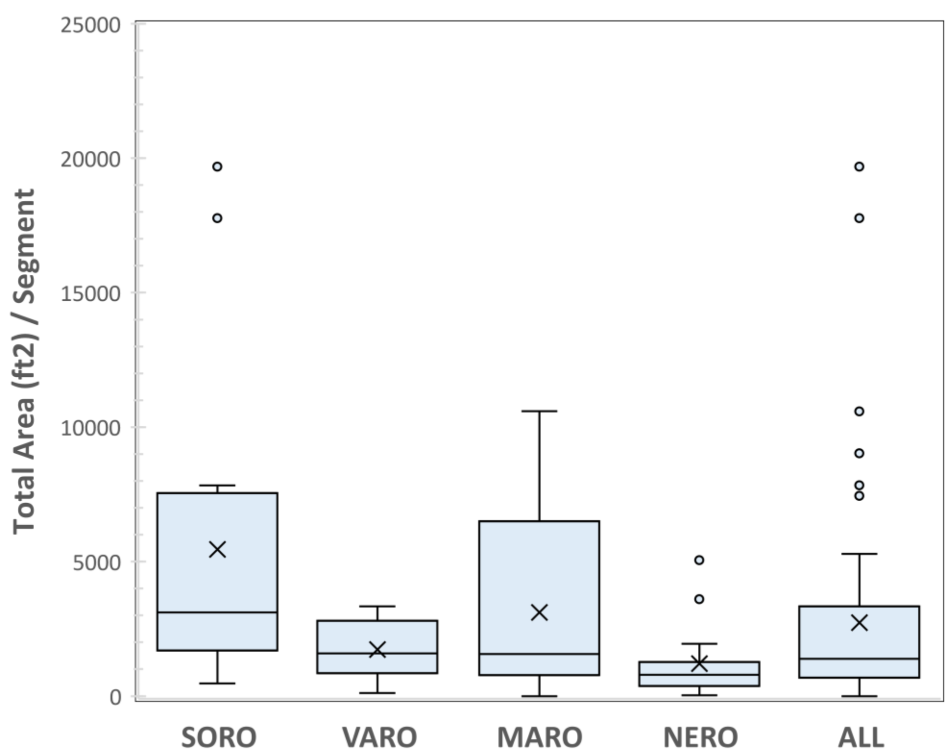


Figure 22. Boxplots illustrating the distribution of values for total area of informal trails for the ATC regions.

ITs were segmented during GPS field surveys based on changing condition classes and width categories. Table 25 presents condition class data for IT linear extent (ft) and areal extent (ft^2), rather than IT segments, whose lengths and widths vary. Based on linear extent for the entire dataset, 22.7% of the ITs have a slight loss of vegetation cover and are barely distinguishable (Table 25). Nearly a third (31.6%) are visually obvious but lightly impacted. About 12.2% show the beginnings of soil loss, but erosion is prevalent on only 8.1%. Based on the sum of Condition Class 4 and 5 percentages, SORO (27.3%) has the most severely impacted ITs, followed by VARO (18%), with NERO having the least impacted ITs (12.3%). The areal extent data is quite similar, though the percentages of ITs shift slightly to the more degraded condition classes when the influence of IT widths is factored in.

The majority of ITs by linear extent are 1-2 ft wide (68.7%), with 19% less than a foot and 12.3% more than 2 ft (Table 26). A substantially greater proportion of ITs in NERO (24.9%) were greater than 2 ft wide than in the other regions, which ranged from VARO (5.6%) to SORO (12.5%).

While many ITs occur along trails to provide access to campsites, water sources, and vistas, some dense networks of ITs form in some locations which are illustrated in two case examples: the Hawk Mountain shelter and associated campsites in GA and through the Laurel Fork Gorge in TN. Data and maps are presented to characterize and illustrate IT-related impacts in these two areas. As shown in Table 27, both case example areas have substantial networks of ITs with summary measures of linear and areal extent that are more than ten times the median values found in the entire A.T. sample. For example, the Hawk Mountain IT network has 2.8 miles of trail and 0.41 acres (Figure 23), while the Laurel Fork Gorge has 2.1 miles of ITs and 0.45 acres (Figure 24).

Table 25. Lineal and areal extent of informal trails by condition class by ATC region.

Condition Class	SORO		VARO		MARO		NERO		ALL	
Linear Extent	**ft**	**%**	**ft**	**%**	**ft**	**%**	**ft**	**%**	**ft**	**%**
1	10,983	20.6	8,113	42.3	6,817	19.5	1,153	9.7	27,066	22.7
2	16,606	31.1	4,230	22.1	11,205	32.1	5,665	47.6	37,706	31.6
3	11,228	21.0	3,365	17.6	12,135	34.8	3,620	30.4	30,348	25.4
4	8,042	15.1	2,015	10.5	3,279	9.4	1,165	9.8	14,501	12.2
5	6,499	12.2	1,446	7.5	1,458	4.2	299	2.5	9,702	8.1
All	**53,359**	**100.0**	**19,169**	**100.0**	**34,894**	**100.0**	**11,902**	**100.0**	**119,323**	**100.0**
Areal Extent	**ft^2**	**%**	**ft^2**	**%**	**ft^2**	**%**	**ft^2**	**%**	**ft^2**	**%**
1	10,569	13.8	7,686	37.0	7,880	15.8	1,585	6.6	27,719	16.2
2	21,849	28.6	4,448	21.4	16,013	32.2	10,698	44.2	53,007	31.0
3	16,135	21.1	3,887	18.7	17,728	35.6	9,262	38.3	47,012	27.5
4	13,010	17.0	2,602	12.5	5,418	10.9	2,063	8.5	23,093	13.5
5	14,823	19.4	2,169	10.4	2,709	5.4	579	2.4	20,280	11.9
All	**76,387**	**100.0**	**20,792**	**100.0**	**49,747**	**100.0**	**24,186**	**100.0**	**171,111**	**100.0**

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

Table 26. Number and percent of informal trails by width class by ATC region.

Average Width (ft)	SORO		VARO		MARO		NERO		ALL	
	ft	%	ft	%	ft	%	ft	%	ft	%
<1	13453	25.2	8624	45.0	680	1.9	109	0.9	22866	19.0
1 – 2	33261	62.3	9469	49.4	30326	86.9	9444	74.2	82500	68.7
>2	6670	12.5	1076	5.6	3888	11.1	3175	24.9	14808	12.3
All	53384	100.0	19169	100.0	34894	100.0	12728	100.0	120174	100.0

Table 27. Lineal and areal extent of informal trails by condition class for the Hawk Mountain Shelter and Laurel Fork Gorge, as compared to median values for the entire A.T. sample.

Condition Class	Hawk Mountain	Laurel Fork	Median Sum ft/ Segment[1]
	Sum Linear Extent (ft)		
1	3,329	3,104	194
2	4,325	4,182	348
3	2,235	1,126	208
4	2,403	1,768	185
5	2,053	824	168
All	**14,345**	**11,004**	**1,043**
Sum Areal Ext. (ft^2)	**17,771**	**19,681**	**1,385**

1 – Values are for the entire A.T. sample for comparison purposes.

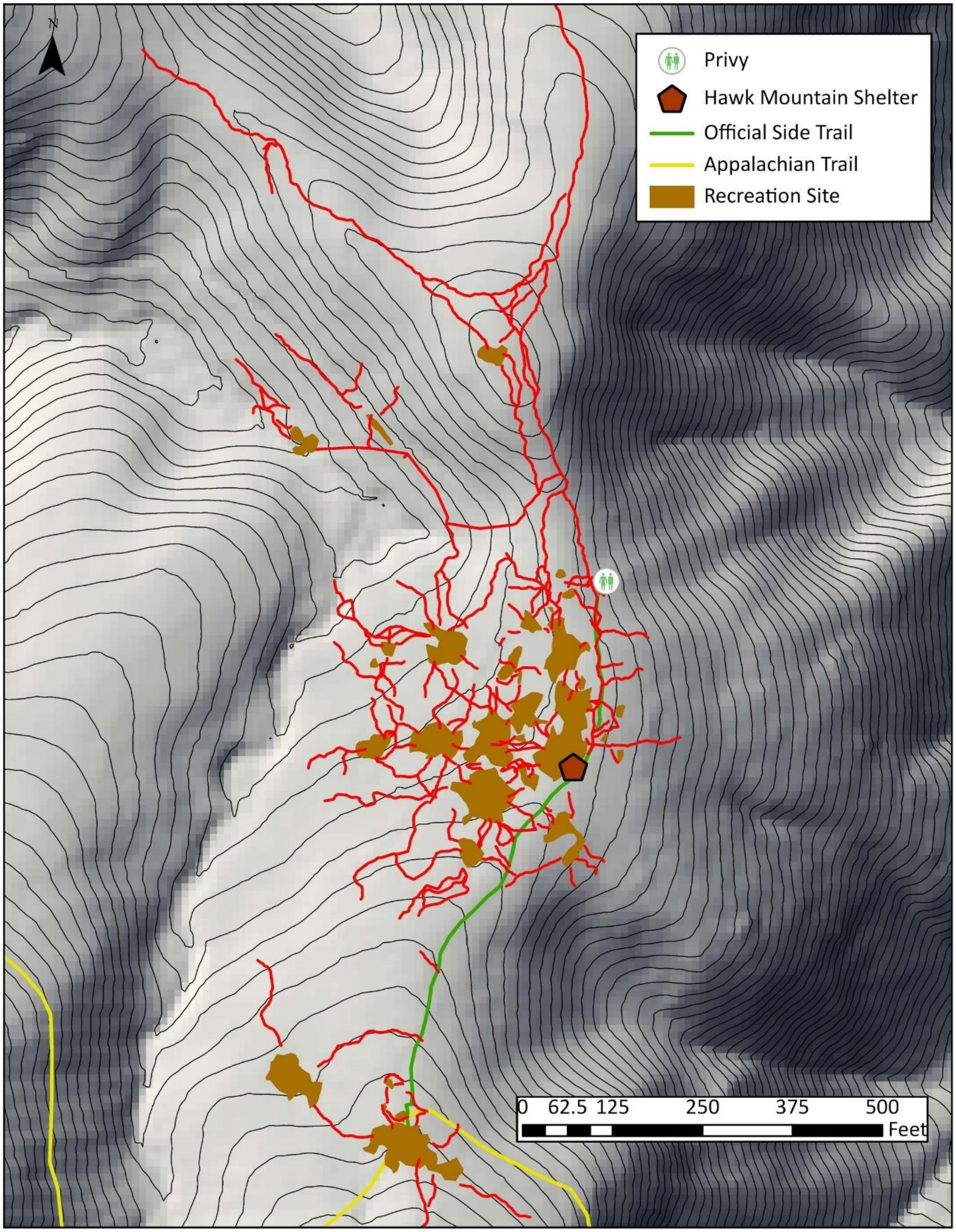


Figure 23. Informal trail network associated with clusters of campsites around the Hawk Mountain Shelter in Georgia.

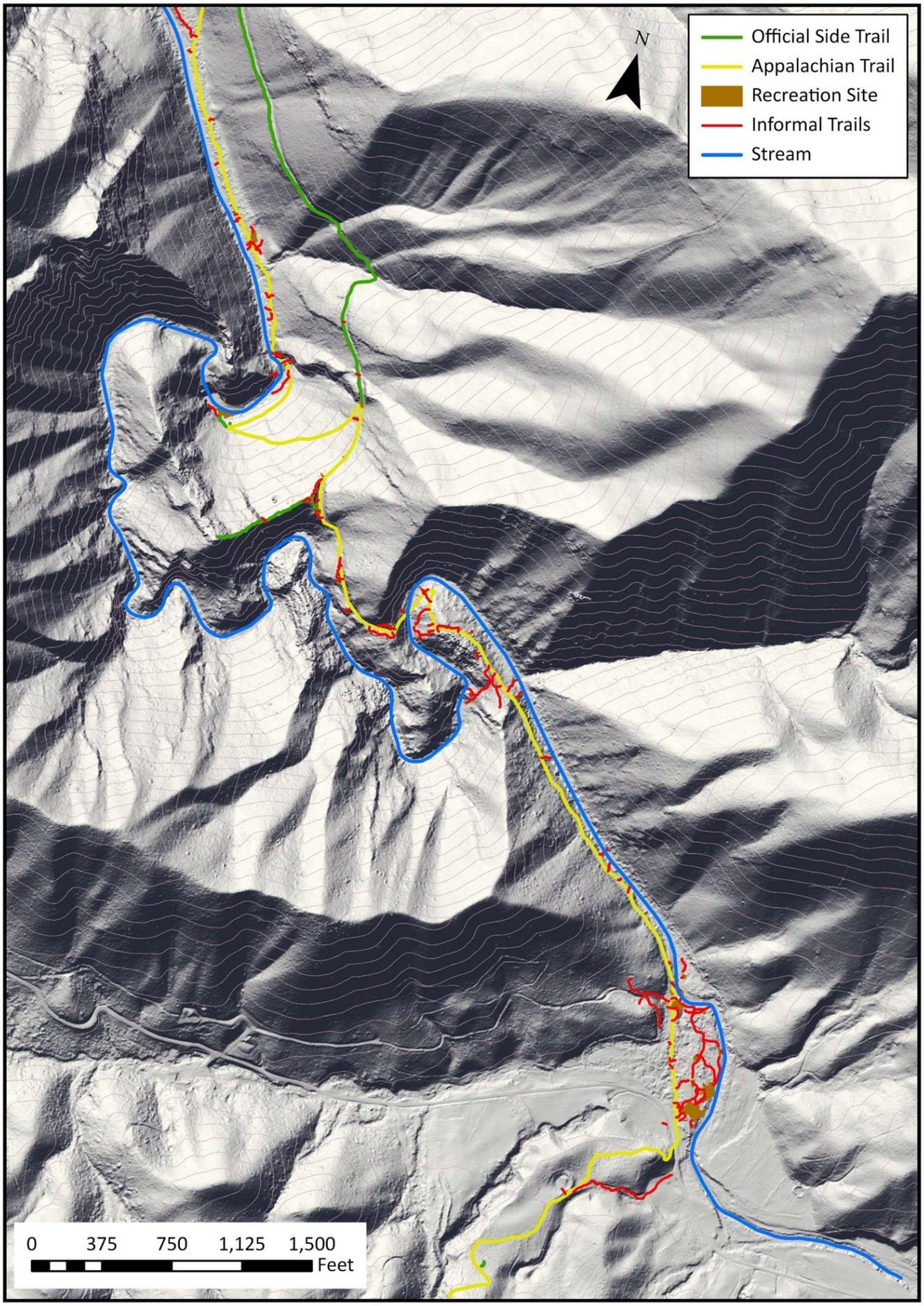


Figure 24. Informal trail network associated with the A.T. in the Laurel Fork Gorge, Tennessee.

Recreation Sites

The following results describe findings from the 731 recreation sites located and assessed within the 63 surveyed segments. Recreation site conditions are first described in relation to the individual recreation site and then for clusters of overnight sites, aggregated based on proximity to one another. Within each section, results describe recreation site attributes (inventory indicators) and recreation site resource conditions (impact indicators).

Recreation sites were defined as nodal areas of visually-obvious vegetation and/or substrate disturbance within the sampled A.T. corridor created by human trampling during overnight or day-use activity. Seven types of recreation sites were defined and inventoried:

Overnight sites – including shelter sites, campsites, side-hill campsites, and sites on woods roads, and

Day-use sites – including vistas, trail junctions or rest stops, and combination sites.

As described in the Methods section, our study captured a random spatially-distributed 9% sample of the entire A.T., assessing 63 5 km (3.1 mi) segments, including 196 mi of the 2,190 mi A.T. These data therefore capture a representative sample of the entire A.T. that can be used to characterize baseline conditions for the A.T. tread and for associated recreation sites and informal trails. For example, Table 28 reports the numbers of overnight and day-use recreation sites stratified by type yielded by our representative sample, which can be used to extrapolate estimates of each site type for the entire A.T.

These data suggest there are about 5,251 campsites along the A.T., including about 726 constructed side-hill campsites (Table 28). Similarly, extrapolation of our data suggests there are an estimated 2,356 day-use recreation sites within the A.T. corridor, including 1,363 that field staff classified as resting/lunch spots, 838 vistas, and 335 combinations with some that had fire rings indicating they may also have been used for overnight camping.

Table 28. Number of sampled recreation sites by type with extrapolations to the full A.T. (based on a 9% sample of 196 of the A.T.'s 2,190 miles).

Site Type	9% Sample (N)	Extrapolation Coefficient	Full A.T. Estimate (N)
Overnight Sites	504		5,529
Shelters/Huts/Lean-tos	34		278[1]
Campsites	405	1 per 0.484 mi	4,525
Side-hill Campsites	53	1 per 3.698 mi	592
Side-hill Campsites on Rd	12	1 per 16.333 mi	134
Day-Use Recreation Sites	227		2,356
Vista	75	1 per 2.613 mi	838
Resting/Lunch	122	1 per 1.607 mi	1,363
Combination	30	1 per 6.533 mi	335
Totals	731		7,885

1 – There are approximately 278 shelters/huts/lean-tos on the A.T.

Inventory Indicators

GPS points and boundaries are "missing" for 2 of the 731 sites so any GIS-calculated indicators in this and following sections are also missing 2 (N=729).

Distance to Nearest Site

Potential for visitor solitude and privacy was assessed in GIS by measuring the distance from each recreation site to its nearest neighboring recreation site using site boundaries. Note, when interpreting these values note that near the ends of our study segments some sites may be closer to sites we did not survey just outside the segment boundary. Recreation site distances to the nearest other site boundaries ranges from 0-9,670 ft with a mean of 454 ft and a median of 104 ft (Table 29).

About one-third (36%) of all sites are within 50 ft of another site, 49% of sites are within 100 ft of another site and 70% are within 300ft (Table 30). For context, Daniels and Marion (2006) determined that normal conversation could not be clearly heard or interpreted, and inter-site visibility is reduced at about 100 ft in Eastern forests. Shelters provide the least solitude, with 92% of shelter sites within 100 ft of another site. Forty-seven percent of campsites are within 100 ft of another site and 74% of side-hill campsites are within 50 ft of another site.

Inter-site distances are closest in the northern and southern management regions, with 69% of overnight sites in SORO within 100 ft of each other and 64% of sites in NERO within 100 ft of each other (Table 31).

Distance to the A.T.

The shortest distance between recreation site boundaries to the A.T. tread was also measured in GIS to characterize recreation site locations relative to the trail and the potential for hikers to experience natural scenery and solitude. As this was measured sight unseen, recreation sites may or may not be visible from the trail depending on vegetative screening and topography.

Recreation site distance to the A.T. tread ranges from 0-1,340 ft with a mean of 1140 ft and median of 26 ft (Table 29). Seventy percent of all recreation sites are within 100 ft of the A.T. and 61% of campsites are within 50 ft (Table 30). Interestingly, shelter and side-hill campsite types, located and constructed by managers/volunteers, have the largest percentages of sites located further than 300 ft from the A.T., 32% and 72% respectively. Regardless, most overnight sites (83%) and day-use sites (64%) are within 50 ft of the A.T. (Table 30).

Distance to Shelter

This indicator represents the distance from the boundary of each recreation site to the GPS point of the shelter itself, not a shelter site's outer boundaries which may include small or large contiguous areas used for tent camping. Therefore, distances from separate recreation sites to the shelter GPS points can reflect longer distances. The majority (78%) of all recreation sites are further than 300 ft from a shelter (Table 30). The closest site types are side-hill sites and campsites, with 29% and 17%, respectively, within 200 ft from shelters.

Site Expansion Potential

Site expansion potential was rated in the field using three categories (poor, moderate, high), also referencing the extent to which features in adjacent offsite areas would constrain campsite expansion, including slope, rockiness, vegetation density, and/or drainage. For example, a "poor" expansion potential rating means that the offsite areas would deter visitors from camping outside existing site boundaries and limiting future site expansion. It is also worth emphasizing that this indicator is based on **existing** site boundaries; even large sites that have expanded to the furthest extent of flat terrain could still have a poor rating.

Campsite and shelter site types are about equally split between good, moderate, and poor ratings. However, side-hill campsites, purposefully selected to avoid site expansion problems, were predominantly rated poor (79%) or moderate (13%) (Table 30). Most side-hill campsites on old woods roads were rated moderate (58%), likely reflecting the fact that while steeper terrain may exist above and below the road, these campsites can still expand laterally along the side-hill roads.

Table 29. Mean, median, and range data for different types of overnight and day-use sites.

Inventory Indicators	Overnight Sites				Day-Use Sites			
	Shelters	Campsites	Side-hill Campsites	Side-hill Rd Campsites	Vista Sites	Resting & Lunch Sites	Combo Sites	All Sites
Distance to Nearest Site (ft)								
Median	31	120	33	118	155	239	36	104
Mean	148	444	132	1160	478	664	322	454
Range	1-3,206	0-9,143	0-4,445	26-7,657	2-3,206	0-9,670	0-5,497	0-9,670
Distance to A.T. (ft)								
Median	195	32	524	64	7	6	15	26
Mean	253	121	523	221	54	58	100	140
Range	0-968	0-1,340	0-1,097	0-888	0-410	0-996	0-570	0-1,340
Distance to Shelter[2] (ft)								
Median	0	4,191	3,106	5,063	4,559	4,243	3,374	3,724
Mean	13	6,785	2,481	5,865	6,224	5,972	5,194	5,882
Range	0-130	0-45771	27-14,706	82-14,607	161-19,005	79-45,573	13-25,728	0-45,771

Tree Canopy Cover

Experimental trampling studies reveal that grasses and sedges are highly resistant and resilient to trampling in sunny meadows and somewhat less so in open forests; however, they are intolerant of shade and provide little cover under full tree canopies (Cole, 1995; Hill and Pickering, 2009). In contrast, herbs, which have low resistance and resilience to trampling, reach their greatest cover in forests with 25-50% canopy cover and decline to limited cover under the densest canopies.

In our sample, 60% of recreation sites are located under forest canopies with greater than 75% cover (Table 30). Two categories of recreation sites are skewed more toward sunny or open forest conditions. Vistas are predominantly in open settings, 63% located in 0-5% canopy cover. These are mostly naturally-occurring openings, though vista management efforts do sometimes remove obstructing trees. Surprisingly, shelters are also in sunny settings, 26% have 0-5% canopy cover and 21% have 6-25% canopy cover. Field observations reveal that most shelters were originally located under full canopies, but intensive camping activity and natural processes over many decades caused substantial tree damage, mortality, and felling without replacement. This process is corroborated from a 32-year study of campsites in the Boundary Waters Canoe Area Wilderness, where tree loss on campsites shifted the composition of ground vegetation from shade-tolerant herbs to sun-loving and trampling resistant grasses and non-native herbs (Eagleston and Marion, 2017). In contrast, there is little visitor-induced tree mortality on day-use sites lunch/resting sites, 68% of which have tree canopy cover exceeding 75% (Table 30). Similarly, 70% of campsites are located under tree canopy cover exceeding 75%.

Table 30. Number and percent of recreation sites by site type for various inventory indicators.

Inventory Indicators	Overnight Sites								Day-Use Sites							
	Shelters		Campsites		Side-hill Campsites		Side-hill Rd Campsites		Vista Sites		Resting & Lunch Sites		Combo Sites		All Sites	
	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
Distance to Nearest Site (ft)																
<50	25	74	140	35	39	74	1	8	21	28	20	16	17	57	**263**	**36**
51-100	6	18	47	12	10	19	5	42	8	11	14	11	3	10	**93**	**13**
101-200	1	3	58	14	2	4	1	8	11	15	22	18	3	10	**98**	**13**
201-300	0	0	33	8	0	0	0	0	9	12	14	11	3	10	**59**	**8**
>300	2	6	126	31	2	4	5	42	25	34	52	43	4	13	**216**	**30**
Totals	34	100	404	100	53[1]	100	12	100	74	100	122	100	30	100	**729**	**100**
Distance to A.T. (ft)																
<50	10	29	246	61	5	9	6	50	55	74	105	86	18	60	**445**	**61**
51-100	3	9	49	12	3	6	1	8	4	5	3	2	2	7	**65**	**9**
101-200	4	12	42	10	1	2	1	8	9	12	5	4	4	13	**66**	**9**
201-300	6	18	17	4	6	11	0	0	3	4	3	2	4	13	**39**	**5**
>300	11	32	50	12	38	72	4	33	3	4	6	5	2	7	**114**	**16**
Totals	34	100	404	100	53	100	12	100	74	100	122	100	30	100	**729**	**100**
Distance to Shelter[2] (ft)																
<50	N.A.		7	2	2	4	0	0	0	0	0	0	2	7	**43**	**6**
51-100			19	5	4	8	1	8	0	0	1	1	2	7	**27**	**4**
101-200			40	10	9	17	0	0	2	3	2	2	4	13	**59**	**8**
201-300			22	5	4	8	0	0	1	1	3	2	1	3	**31**	**4**
>300			316	78	34	64	11	92	71	96	116	95	21	70	**569**	**78**
Totals			404	100	53	100	12	100	74	100	122	100	30	100	**729**	**100**
Site Expansion Potential																
Good	10	29	137	34	4	8	1	8	9	12	19	16	7	23	**187**	**26**
Moderate	12	35	151	37	7	13	7	58	9	12	48	39	8	27	**242**	**33**
Poor	12	35	117	29	42	79	4	33	57	76	55	45	15	50	**302**	**41**
Totals	34	100	405	100	53	100	12	100	75	100	122	100	30	100	**731**	**100**
Tree Canopy Cover (%)																
0-5	9	26	20	5	0	0	0	0	47	63	14	11	3	10	**93**	**13**
6-25	7	21	13	3	2	4	0	0	4	5	4	3	3	10	**33**	**5**
26-50	4	12	22	5	1	2	0	0	10	13	6	5	4	13	**47**	**6**
51-75	7	21	66	16	9	17	2	17	7	9	16	13	11	37	**118**	**16**
76-95	6	18	201	50	31	58	10	83	6	8	52	43	7	23	**313**	**43**
96-100	1	3	83	20	10	19	0	0	1	1	30	25	2	7	**127**	**17**
Totals	34	100	405	100	53	100	12	100	75	100	122	100	30	100	**731**	**100**

1 - 31 of the 53 side hill campsites are from one grouping, the new Hawk Mountain side-hill sites.
2 - This represents the distance to the GPS point of the shelter itself, not a site with a shelter on it (i.e. Shelter site type).

Of the overnight sites, 183 (25%) are in SORO, 101 (14%) are in VARO, 129 (18%) are in MARO, and 91 (12%) are in NERO (Table 31). Interestingly, approximately half of overnight sites are less than 50 ft from the nearest other site in SORO and NERO but only 15% are this close in VARO and 30% in MARO. For overnight site distance to the A.T., the percentage of sites <50 ft ranged from a low of 48% in SORO to a high of 67% in VARO. NERO sites tend to be located closer to shelters (16% <50 ft) as compared to the other regions (5-7% <50 ft) (Table 31). Ratings for site expansion potential indicate that day-use sites are more susceptible than overnight sites, with 56% rated as poor vs 35% for overnight sites. For overnight sites approximately one-third were rated in each category, while regional data indicate that the most expansion prone sites are in NERO (57% rated as good expansion potential), to 18% in SORO. Tree canopy cover is denser on overnight sites, with 10% having less than 25% tree cover, compared to 33% of day-use sites having less than 25% tree cover. Sites with low tree cover can support more extensive cover of shade-intolerant grasses and sedges, which are more trampling resistant than forest herbs.

Table 31. Number and percent of overnight recreation sites by ATC Region, with summary statistics for day-use and overnight sites for various inventory indicators.

Inventory Indicators	ATC Management Region[1]								Site Type				All Sites	
	SORO		VARO		MARO		NERO		Day-Use		Overnight			
	N	%	N	%	N	%	N	%	N	%	N	%	N	%
Distance to Nearest Site (ft)														
<50	101	55	15	15	39	30	50	55	58	26	205	41	**263**	**36**
50-100	26	14	14	14	20	16	8	9	25	11	68	14	**93**	**13**
100-200	12	7	26	26	14	11	10	11	36	16	62	12	**98**	**13**
200-300	12	7	9	9	6	5	6	7	26	12	33	7	**59**	**8**
300+	32	17	37	37	49	38	17	19	81	36	135	27	**216**	**30**
Totals	183	100	101	100	128	100	91	100	226	100	503	100	**729**	**100**
Distance to A.T. (ft)														
<50	87	48	68	67	66	52	46	51	178	79	267	53	**445**	**61**
50-100	19	10	18	18	16	13	3	3	9	4	56	11	**65**	**9**
100-200	18	10	4	4	15	12	11	12	18	8	48	10	**66**	**9**
200-300	13	7	3	3	9	7	4	4	10	4	29	6	**39**	**5**
300+	46	25	8	8	22	17	27	30	11	5	103	20	**114**	**16**
Totals	183	100	101	100	128	100	91	100	226	100	503	100	**729**	**100**
Distance to Shelter (ft)														
<50	13	7	6	6	7	5	15	16	2	1	41	8	**43**	**6**
50-100	9	5	3	3	3	2	9	10	3	1	24	5	**27**	**4**
100-200	20	11	5	5	17	13	9	10	8	4	51	10	**59**	**8**
200-300	8	4	3	3	8	6	7	8	5	2	26	5	**31**	**4**
300+	133	73	84	83	93	73	51	56	208	92	361	72	**569**	**78**
Totals	183	100	101	100	128	100	91	100	226	100	503	100	**729**	**100**
Site Expansion Potential														
Good	33	18	26	26	41	32	52	57	35	15	152	30	**187**	**26**
Moderate	78	43	34	34	47	36	18	20	65	29	177	35	**242**	**33**
Poor	72	39	41	41	41	32	21	23	127	56	175	35	**302**	**41**
Totals	183	100	101	100	129	100	91	100	227	100	504	100	**731**	**100**
Tree Canopy Cover (%)														
0-5	5	3	10	10	2	2	12	13	64	28	29	6	**93**	**13**
6-25	3	2	4	4	6	5	9	10	11	5	22	4	**33**	**5**
26-50	5	3	2	2	5	4	15	16	20	9	27	5	**47**	**6**
51-75	33	18	13	13	20	16	18	20	34	15	84	17	**118**	**16**
76-95	105	57	46	46	67	52	30	33	65	29	248	49	**313**	**43**
96-100	32	17	26	26	29	22	7	8	33	15	94	19	**127**	**17**
Totals	183	100	101	100	129	100	91	100	227	100	504	100	**731**	**100**

1 – ATC Regional Offices, SORO = Southern (GA, NC, TN), VARO = Virginia (Southwest & Central VA), MARO = Mid-Atlantic (WV, MD, PA, NJ, NY), NERO = New England (CT, MA, VT, NH, ME).

Impact Indicators

Condition Class

Condition Class ratings provide a single categorical assessment of site conditions based on five ranked descriptive classes of resource impact. Our Condition Class ratings focus on changing groundcover conditions, from a Class 1 site with minimal vegetation and organic litter disturbance, to a Class 5 site with nearly complete loss of vegetation cover, organic litter, and obvious soil erosion in places (Table 32). Five quantitative measures of groundcover conditions are also included in Table 32 to numerically characterize these changes.

A common problem with rating systems is that large numbers/percentages of sites can cluster in one or two of the categories, indicating they have been too broadly defined and are not sensitive to any but large changes in resource conditions. Fortunately, the A.T. recreation sites are well-distributed across the ratings, dropping only at the two extremes (Table 32). Just over a third (36%) of sites are minimally disturbed, with a rating of Class 1 (9%) or Class 2 (27%). One-quarter of the sites (26%) are rated as Class 3, characterized by the trampling and loss of vegetation over most of the site and exposure of soil in the primary use areas. One-fifth of the sites (21%) are rated Class 4, with widespread soil exposure, and only 67 sites (9%) are rated as Class 5, which additionally has obvious erosion, as indicated by exposed tree roots and/or gullying. Recreation sites on mostly bedrock or rocky areas (N=57, 8%) were assigned a separate rating due to their minimal vegetation, organic litter, and soils (Table 32).

Table 32. Condition Class ratings for all recreation sites, including descriptive data for several impact indicators.

Condition Class[1]	All Sites		Site Size (ft^2)	Vegetation Loss (%)	Vegetation Loss (ft^2)	Exposed Soil (%)	Exposed Soil (ft^2)
	#	%	Median	Median	Median	Median	Median
1	69	9	211	23	37	3	10
2	201	27	336	60	163	3	19
3	187	26	538	60	257	38	98
4	150	21	386	70	226	63	246
5	67	9	1,304	83	829	86	813
R	57	8	243	83	107	3	13

1 - **Class 1**: Site barely distinguishable; slight loss of vegetation cover and /or minimal disturbance of organic litter.
Class 2: Site obvious; vegetation cover lost and/or organic litter pulverized in primary use areas.
Class 3: Vegetation cover lost and/or organic litter pulverized on much of the site, some bare soil exposed in primary use areas.
Class 4: Nearly complete or total loss of vegetation cover and organic litter, bare soil widespread.
Class 5: Soil erosion obvious, as indicated by exposed tree roots and rocks and/or gullying.
Rock (R): Site is predominantly on rock surfaces, so the effects of trampling are difficult to see/assess.

Note that site sizes are often not well-correlated with condition classes (Table 32). Extremely large sites in flat terrain allow the dispersal of camping activities such that only a few core areas lose all their vegetation and organic litter, while in mountainous terrain smaller well-used sites constrained by topography can easily reach a Class 4 rating. Mean and median values for percent and area of vegetation loss and exposed soil are presented in Table 32 as an aid in further characterizing these Condition Classes. Median percent vegetation loss increases from 23% on Class 1 sites to 83% on Class 5 sites, in synch with areal measures that increase from 37 ft^2 to 829 ft^2. Similarly, mean values for percent exposed soil trend from 3% to 86% across Condition Classes, while areal measures of exposed soil trend from 10 ft^2 to 813 ft^2 (Table 32).

Site Size

Recreation sites (all types) range in size from 8 to 16,190 ft^2 with a median of 400 ft^2 (Table 33, Figure 25). The 16,190 ft^2 site is a vista that is mostly open exposed rock but with enough wear to vegetation and lichen to consider it as a single exceptionally large site. The total or aggregate area of disturbance from all recreation sites is 676,171 ft^2 (Table 33), equivalent to a total of 15.5 acres and 29 ft^2 of impact on a per acre basis within our sampled study segments. Extrapolating these sample data to the entire A.T. yields an estimated aggregate area of disturbance for all recreation sites of 7,513,011 ft^2, equivalent to 172.4 acres. This breaks down to 1,513,646 ft^2 (34.7 acres) for day-use sites and 5,999,365 ft^2 (137.7 acres) for overnight sites. Most recreation sites are relatively small, 56% of sites are less than 500 ft^2 and 83% are less than 1500 ft^2 (

Table 34, Figure 25). Unfortunately, 13% of sites (N=95) are greater than 2000 ft^2, which we define here as "mega-sites." They occur in all regions though SORO has twice as many as MARO and NERO, while VARO only has 12 (

Table 34). Most of these mega-sites are campsites (57) or shelter sites (23).

To compare the aggregate areal extent of overnight camping impact by region a ft^2/acre measure was computed from sample data as described in Table 35. These data reveal that camping disturbance is more than twice as extensive in SORO (44 ft^2/acre) as compared to VARO and MARO (21 ft^2/acre), with NERO (12 ft^2/acre) having the lowest value (12 ft^2/acre).

Overnight site sizes range from 8 to 8,332 ft^2 with a median of 536 ft^2, while day-use sites range from 8 to 16,190 ft^2 with a median of 219 ft^2 (Table 36). Overnight recreation sites (504, 69%) account for 80% of the aggregate area of impact for all site types, while day-use sites (227, 31%) account for the remaining 20% of impact (Table 36). Shelter sites have substantially larger median sizes (2,688 ft^2) than all other categories of sites, the second largest of which were campsites, with a median size of 562 ft^2 (Table 33). The smallest were resting/lunch sites (175 ft^2) and side-hill campsites (253 ft^2). Median overnight site sizes are largest in SORO, 609 ft^2, and smallest in NERO, 445 ft^2 (Table 36).

Data on the distribution of recreation site sizes is illustrated in Figure 25, with bars notated by the number and cumulative percent of sites in each size class. This format illustrates the distribution of values and facilitates the selection of indicator thresholds or standards in a process like VUM. For example, managers may consider that a 1000 ft^2 campsite (about 32x32 ft) should be sufficiently large for all but large groups of campers. If this value were chosen as a management threshold, data in Figure 25 reveal that 25% of the recreation sites (N=185) would exceed this standard. Similarly, if 2000 ft^2 were selected, 13% of sites (N=95) would exceed the standard.

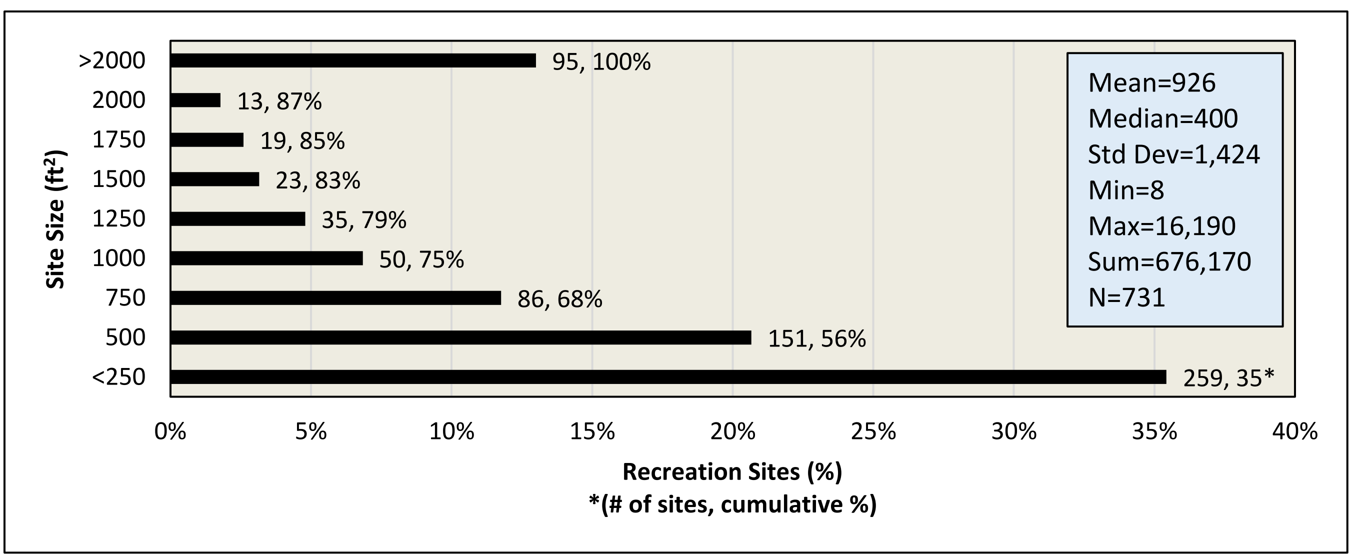


Figure 25. Frequency distribution and descriptive statistics for recreation site size.

Interestingly, 14.9% of the aggregate area of recreation site impact is in designated wilderness, while 9.4% of our sampled segments are in wilderness; 7.4% of the A.T. is in Wilderness.

Table 33. Descriptive statistics for recreation sites by site type for various impact indicators.

Impact Indicators	Overnight Sites				Day-Use Sites			All Sites
	Shelters	Campsites	Side-hill Campsites	Side-hill Rd Campsites	Vista Sites	Resting & Lunch Sites	Combo Sites	
N	**35**	**404**	**53**	**12**	**75**	**122**	**30**	**731**
Site Size (ft^2)								
Median	2,688	562	253	430	304	175	326	**400**
Sum	103,054	405,400	23,205	8,280	81,534	34,461	20,236	**676,171**
Range	536-7,924	8-8,332	64-5,011	102-3,760	26-16,190	8-2,047	8-3,074	**8-16,190**
Vegetation Loss (ft^2)								
Median	1,203	251	165	195	108	98	149	**183**
Sum	56,115	221,615	14,545	5,336	42,153	22,137	12,342	**374,243**
Range	-568-4,441	-1,918-7,634	24-2,802	48-2,632	-523-9,714	0-1,689	-77-2,152	**-1,918-9,714**
Exposed Soil (ft^2)								
Median	1,409	82	162	71	34	39	54	**72**
Sum	54,546	147,003	15,379	2,583	8,765	14,154	5,912	**248,342**
Range	163-6,276	0-6,264	9-3,157	3-1,429	1-3,338	1-1,412	1-1,937	**0-6,276**
Damaged Trees (#)								
Median	3.0	1.0	0.0	0.0	0.0	0.0	0.0	**0.0**
Sum	160	844	52	4	25	27	44	**1,156**
Range	0-17	0-63	0-16	0-1	0-9	0-7	0-12	**0-63**
Exposed Roots (#)								
Median	2.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
Sum	134	669	66	8	70	77	53	**1,077**
Range	0-20	0-21	0-17	0-4	0-12	0-9	0-8	**0-21**
Fire Rings (#)								
Median	1.0	1.0	0.0	0.0	0.0	0.0	0.5	**1.0**
Sum	31	175	13	5	2	3	5	**234**
Range	0-3	0-6	0-2	0-2	0-2	0-1	0-1	**0-6**
Stumps (#)								
Median	2.0	0.0	0.0	0.5	0.0	0.0	0.0	**0.0**
Sum	150	784	31	14	97	73	127	**1,276**
Range	0-21	0-40	0-6	0-7	0-30	0-21	0-49	**0-49**
Access trails (#)								
Median	4.0	2.0	1.0	1.0	1.0	1.0	1.0	**1.0**
Sum	168	867	74	25	110	167	43	**1,454**
Range	1-17	0-18	1-5	1-8	0-3	1-5	1-5	**0-18**

Table 34. Number and percent of recreation sites by ATC region and recreation site type for categories of site size.

Site Size (ft²)	Region								Use Type[1]														Totals	
	SORO		VARO		MARO		NERO		S		C		SHC		SHR		V		R		U			
	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
<250	111	15	44	6	51	7	53	7	0	0	100	14	25	3	3	0	34	5	86	12	11	2	**259**	**35**
500	53	7	39	5	34	5	24	3	0	0	86	12	22	3	5	1	12	2	19	3	6	1	**150**	**21**
750	40	5	9	1	21	3	16	2	2	0	59	8	3	0	2	0	5	1	9	1	6	1	**86**	**12**
1000	18	2	12	2	13	2	7	1	0	0	42	6	0	0	1	0	6	1	1	0	0	0	**50**	**7**
1250	13	2	6	1	6	1	10	1	4	1	24	3	0	0	0	0	5	1	1	0	1	0	**35**	**5**
1500	3	0	5	1	7	1	8	1	2	0	13	2	1	0	0	0	2	0	3	0	2	0	**23**	**3**
1750	7	1	6	1	6	1	0	0	1	0	15	2	0	0	0	0	0	0	2	0	1	0	**19**	**3**
2000	4	1	1	0	5	1	3	0	2	0	9	1	0	0	0	0	2	0	0	0	0	0	**13**	**2**
>2000	42	6	12	2	20	3	21	3	23	3	57	8	2	0	1	0	8	1	1	0	3	0	**95**	**13**

1 – S = Shelters, C = Campsites, SHC = Side-hill Campsites, SHR = Side-hill Rd Campsites, V = Vistas, R = Resting & Lunch Sites, U = Combination Sites.

Table 35. Area of overnight camping disturbance per acre by ATC region, with computation data[1].

ATC Region	Segment (acres)	Segments (#)	Total Acres Surveyed	Aggregate Impact (ft²)	ft²/acre
SORO	371	14	5,194	227,788	44
VARO	371	12	4,452	91,364	21
MARO	371	16	5,936	126,438	21
NERO	371	21	7,791	94,349	12
All	371	**63**	**23,373**	**539,939**	**23**

1 – ATC region data for overnight sites, which have different numbers of sampled segments. Comparable data for the areal extent of overnight sites (ft²/acre) was computed by multiplying the acres/segment by number of segments and dividing by the aggregate area of overnight impact.

Table 36. Descriptive statistics for overnight recreation sites by ATC region, and summary statistics for day-use and overnight sites for various impact indicators.

Impact Indicators	ATC Management Region[1]				Site Type		All Sites
	SORO	VARO	MARO	NERO	Day-Use	Overnight	
N	**183**	**101**	**129**	**91**	**227**	**504**	**731**
Site Size (ft²)							
Median	609	482	535	445	219	536	**400**
Sum	227,788	91,364	126,438	94,349	136,232	539,939	**676,171**
Range	36 - 7,993	8 - 8,332	32 - 5,562	37 - 7,924	8 – 16,190	8 - 8,332	**8 – 16,190**
Vegetation Loss (ft²)							
Median	415	201	245	158	107	245	**183**
Sum	150,430	48,031	61,003	38,147	76,632	297,611	**374,243**
Range	0 – 7,634	-237 – 3,169	-1,918 – 3,819	-568 – 4,968	-523 – 9,714	-1,918 – 7,634	**-1,918 – 9,714**
Exposed Soil (ft²)							
Median	325	77	47	17	37	108	**72**
Sum	136,244	38,075	27,638	17555	28,831	219,511	**248,342**
Range	1 – 6,276	0 – 3,264	1 – 2,681	2 - 2090	1 – 3,338	0 – 6,276	**0 – 6,276**
Damaged Trees (#)							
Median	1	0	0	1	0	1	**0**
Sum	456	156	199	249	96	1060	**1,156**
Range	0 - 23	0 - 63	0 - 13	0 - 31	0 – 12	0 - 63	**0 – 63**
Exposed Roots (#)							
Median	1	0	0	0	0	0	**0**
Sum	449	108	233	87	200	877	**1,077**
Range	0 - 21	0 - 20	0 - 20	0 - 9	0 – 12	0 - 21	**0 – 21**
Fire Rings (#)							
Median	1	1	1	0	0	1	**1**
Sum	100	67	119	37	10	323	**333**
Range	0 - 2	0 - 2	0 - 6	0 - 2	0 – 2	0 - 6	**0 – 6**
Stumps (#)							
Median	0	0	0	1	0	0	**0**
Sum	418	116	185	260	297	979	**1,276**
Range	0 - 23	0 - 16	0 - 12	0 - 40	0 – 49	0 - 40	**0 - 49**
Access trails (#)							
Median	2	1	2	1	1	2	**1**
Sum	533	189	273	137	320	1,132	**1,454**
Range	0 - 18	0 - 8	0 - 10	0 - 7	0 – 5	0 - 18	**0 – 18**

1 – S = Shelters, C = Campsites, SHC = Side-hill Campsites, SHR = Side-hill Rd Campsites, V = Vistas, R = Resting & Lunch Sites, U = Combination Sites.

Vegetation Loss

The area over which vegetation cover has been lost on recreation sites was estimated through calculations using on- and off-site vegetation estimates and campsite size measures (see Methods). Median area of vegetation loss is 183ft², ranging from a gain of 1,918 ft² to a loss of 9,714 ft² (Table 33).

Median percent *vegetation cover* on recreation sites is 16%, while median vegetation cover on adjacent undisturbed off-site control or “reference” areas is 86%. The difference, median *percent vegetation loss*, is 61%, calculated by subtracting onsite vegetation cover from offsite values, providing an estimate of the percent vegetation loss that has occurred on a recreation site. Recreation sites can gain vegetation cover compared to controls when the removal of tree canopies over time allows enough sunlight penetration to support increased cover of trampling resistant grasses and sedges, resulting in greater cover than originally occurred on the site when forested. Note that negative values represent a "gain" in vegetation cover on campsites because onsite vegetation cover is subtracted from offsite control values. Values for these percentage measures of vegetation cover and loss are not included in report tables because areal measures of vegetation loss, i.e., the estimated area of recreation sites over which vegetation cover has been lost, are deemed as more managerially relevant than percent measures. For example, a manager should be more concerned with losing 50% of the vegetation cover on a 2000 ft^2 site than losing 50% on a 500 ft^2 site. Cole (1989a) provides a more comprehensive discussion of the merits of relying on "*area of vegetation loss*" as the single best vegetative indicator, calculated by multiplying *percent vegetation loss* by recreation site size to provide an estimate of the site area (ft^2) over which vegetation has been lost.

Median area of vegetation loss is 183 ft^2 for all recreation sites and these values are <200 ft^2 for all but two of the recreation site types (Table 33). Median area of vegetation loss increases to 251 ft^2 for campsites but reaches nearly five times this amount for shelter sites (1,203 ft^2). Aggregate area of vegetation loss is 374,243 ft^2 for the entire sample (Table 33), which is 8.6 acres (95.5 acres for the entire A.T.). Median area of vegetation loss is only 107 ft^2 on day-use sites, and more than double that (245 ft^2) on overnight sites (Table 36). Within ATC regions, median area of vegetation loss is lowest in NERO (158 ft^2), intermediate in VARO and MARO (201 ft^2 and 245 ft^2), and substantially higher in SORO (415 ft^2) (Table 36).

While 58% of recreation sites have area of vegetation loss values of less than 250 ft^2, 86% have lost less than 1000 ft^2 (Figure 26). However, 44 sites (6%) have lost more than 2000 ft^2 of vegetation cover.

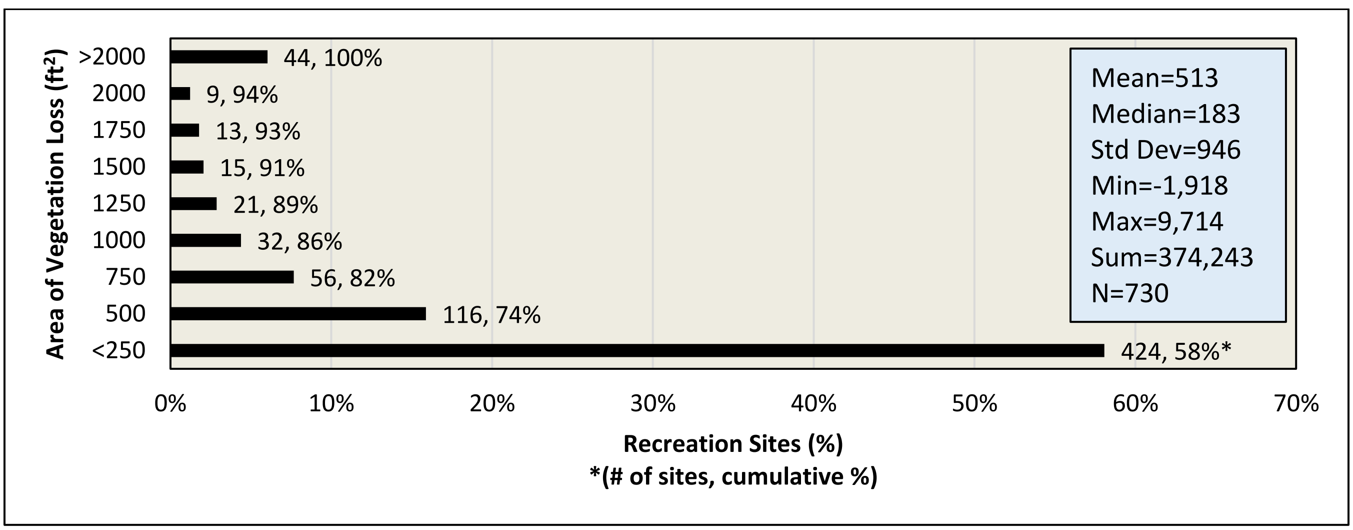


Figure 26. Frequency distribution and descriptive statistics for area of vegetation loss.

Exposed Soil

Exposed soil was assessed using the same pre-defined categories as vegetation loss. Exposed soil is defined as ground with very little or no organic litter (partially decomposed leaf, needle, or twig litter) or vegetation cover, within the site boundaries. Soil exposure does not occur naturally along the A.T. plant communities and all exposed soil is assumed to be caused by trampling of vegetation and organic litter (i.e. offsite soil exposure is assumed to be 0%). Percent soil exposure midpoints were multiplied by the area of the recreation site to determine the area of exposed soil.

Most recreation sites have very little exposed soil 72% of sites have less than 250 ft^2 of exposed soil (Figure 27). However, 10% of sites have 1000 ft^2 or more exposed soil Overall there is a median of 72 ft^2, with a range of 0 to 6,2767 ft^2 (Table 33).

As with site size and area of vegetation loss, shelter sites have the highest median exposed soil as compared to other site types; with a median of 1,409ft^2 (Table 33). Shelter sites have the highest median by over 8 times the next highest. With a median of 325 ft^2 the SORO management region has the highest median per site by over 4 times the next highest median.

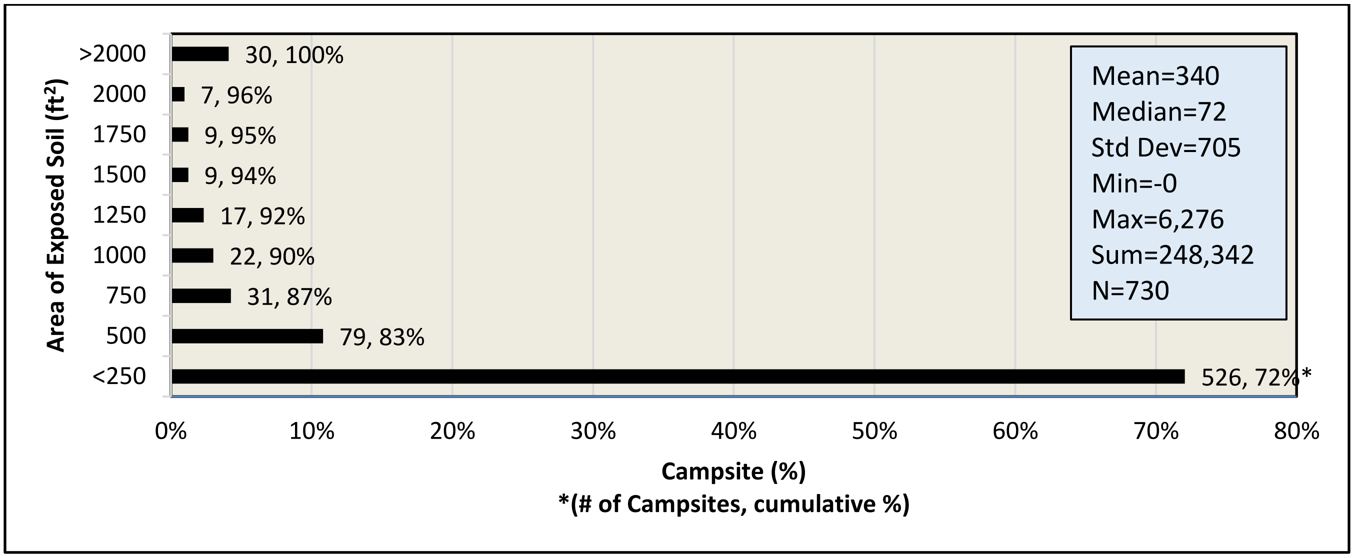


Figure 27. Frequency distribution and descriptive statistics for area of exposed soil.

Damaged Trees

Only live trees within site boundaries were assessed for human-caused damage. Trees were classified as having none or slight damage, moderate damage, or severe damage. Trees with damage in the moderate and severe categories were combined for presentation purposes.

No trees were on 129 (18%) of the recreation sites. No damaged trees were found on 440 (60%) of the recreation sites and 292 (40%) had at least one moderately or severely damaged tree. One hundred fifty-nine (22%) of recreation sites have only one or two damaged trees. Thus, 82% of all sites with trees have 2 or fewer damaged trees. Overall there is a total of 1,156 damaged trees and a median of 0 (Table 33). Most damaged trees were on overnight sites (1,060 damaged trees, 92%). Of the 1,156 trees damaged, 153 were from 5 sites; each having 63, 31, 23, 19, and 17 damaged trees.

Sites that contain a shelter have the highest median tree damage: 3 (Table 33). There are more damaged trees within site boundaries on shelter sites as compared to other site types. Overnight sites have a median of 1 damaged tree and day-use sites have a median of 0 (Table 36). There is a median of 1 damaged tree in both SORO and NERO (Table 36). Median and mean number of damaged trees increases from 2 to 5 with sites that are 2000ft^2 and larger.

Field staff sometimes observed considerably larger numbers of damaged trees in adjacent offsite areas that are not be reflected in these results.

Exposed Roots

Exposed roots reflects soil compaction and soil loss on recreation sites. The exposure of tree roots is often used as a proxy for soil erosion, but because not all campsites have trees within site boundaries it cannot be consistently applied. Again, for presentation purposes, exposed roots in the moderate and severe categories were combined.

Again, no trees were on 129 (18%) of sites. An additional 301 sites (59%) have 0 trees with moderate or severe exposed roots. 102 (14%) sites have one tree with root exposure and 82% of sites have 2 or fewer trees with root exposure.

Shelter sites have a median of 2 trees with exposed roots in the moderate or severe categories, while all other site types have a median of 0 (Table 33). Both overnight and day-use sites have a median of 0 exposed roots per site, with a range from 0 to 21 for overnight and 0 to 12 for day-use (Table 36). SORO has a median of 1 tree per site with exposed roots, the only management region with a median not equal to 0.

Fire Rings

Fire rings were tallied as a count of locations within a site a campfire had been built. This included old, not currently used fire sites but not locations where people had dumped ashes and coals.

This indicator was only calculated for overnight site types. Of the 504 overnight sites, slightly more than half have at least one fire ring; at least one campfire ring is on 57% of sites and 43% have no existing fire rings. 263 (52%) sites have one fire ring and 99% of sites have 2 or fewer rings onsite.

All management regions except for NERO have a median of 1 fire ring (Table 36). Fire ring data is only accurate for a snapshot in time. ATC volunteers and ridge runners may have cleaned up fire rings before the research crew arrived to survey impacts. Number of rings may be an underrepresentation of what may usually be present.

Stumps

All stumps within site boundaries were tallied for each site. No stumps were found on 428 (59%) recreation sites and one stump was found on 102 (14%) of recreation sites. Overall, there is a median on 0 stumps per site with a range of 0 to 49 and a sum of 1,275 (Table 33). There are 30 sites with 10 or more stumps onsite, 18% of sites have 3 or more stumps. Sites with a shelter have a median of 2 stumps and is the only site type with a median other than zero. All regions have a median of 0 except NERO with a median of 1 (Table 36). As for tree damage, field staff also noted the presence of numerous stumps in adjacent offsite areas for some campsites.

Access Trails

Access trails were tallied for every trail radiating from the edge of a recreation site boundary. Although most of the recreation sites have at least one trail leading to them, field staff found 20 sites (3%) that did not. Overall, there is a median of 1 trail, and the number of trails range from 0 to 18 (Table 33). 3% of sites have 0 trails, 51% have 1 trail, 24% have 2 trails and 21% of sites have 3 or more trails. The number of access trails is highest for the shelter site type with a median of 4 trails per site. The SORO and MARO management regions have the highest median number of access trails (median = 2) (Table 36).

Regression Modeling: Campsite Size and Area of Vegetation Loss

Regression modeling was conducted to identify influential factors that affect campsite size and area of vegetation loss on campsites. These analyses and their management implications are described in Arredondo et al. 2020. More than 16 field-collected and GIS-derived indicators, including several new indicators calculated using high-resolution LiDAR topographic data, were evaluated. Chosen variables in the best regression models explained 34% and 28% of the variation in campsite size and area of vegetation loss on campsites. Results identified three key indicators that managers can manipulate to enhance the sustainability of campsites: campsite type, and terrain characteristics relating to landform slope and topographic roughness that inhibit campsite expansion and proliferation. Results support indirect management methods that rely on the location, design, construction, and maintenance of campsites, instead of direct regulations that restrict visitation or visitor freedoms. As visitation pressures continue to increase, this knowledge can be applied to promote the development of more ecologically sustainable campsites.

Clustered Campsites: Analysis of Site Expansion and Proliferation

While campsite expansion and large campsite sizes represent an important management problem, the creation of new campsites by visitors (campsite proliferation) and aggregate camping impact within popular areas are also salient concerns. At the site-level, increasing use often causes site boundaries and areal measures of camping impact to expand. At a somewhat larger scale, considering cumulative impacts at or around an A.T. shelter or for a large cluster of campsites, aggregate campsite impacts increase as campsites *expand in size or proliferate in number* over time (Cole et al, 2008; Leung and Marion, 2004).

$$Aggregate\ Impact = \sum_{i=1}^{N} Campsite\ sizes\ within\ a\ defined\ area_i$$

Using GIS procedures to cluster overnight sites by proximity (distance) allows us to examine how the proliferation of sites influences aggregate impact for a geographic location. For the purposes of this analysis campsites within 100 ft of each other were clustered (associated) with each other (as described in the Methods section). For example, campsites around an A.T. shelter would be grouped and considered part of the "shelter cluster" if the border of a campsite is within 100 ft of the border of the shelter, and any campsite within 100 ft of those campsites are also grouped into that cluster, etc. This linking process continues until no more campsites are within 100 ft of the growing cluster. Note also that isolated campsites located more than 100 ft from other campsites create "clusters" of single sites, including some very large campsites that may have formed when two or more proximate sites merged together.

The clustering process began with 504 overnight campsites from our 9% sample and yielded 272 campsite clusters, which extrapolates to 3,039 clusters for the entire A.T. Table 37 presents data for clustered campsite size categories, revealing that 170 non-shelter campsites, 63% of the 272 clusters, account for only 12.8% of the total camping impact in the 9% sample. In sharp contrast, the 9 campsite clusters with aggregate sizes of >10,000 ft^2 account for 28.4% of the total areal extent of impact within the sample.

Table 37. Number and percent of non-shelter and shelter campsites by clustered campsite size categories.

Clustered Campsite Sizes (ft^2)	Non-Shelter		Shelter		All		Sum	Summary Totals	
	N	%	N	%	N	%	ft^2	Row %	Cumulative %
<1000	170	71	0	0	170	63	69,002	12.8	12.8
1,000-2,000	38	16	0	0	38	14	56,197	10.4	23.2
2,000-4,000	17	7	10	30	27	10	74,982	13.9	37.1
4,000-6,000	4	2	9	27	13	5	64,038	11.9	49.0
6,000-8,000	4	2	2	6	6	2	42,807	7.9	56.9
8,000-10,000	3	1	6	18	9	3	79,710	14.8	71.7
>10,000	3	1	6	18	9	3	153,154	28.4	100.0
All	239	100	33	100	272	100	539,889	100.0	

Table 38 presents data for clustered campsites based on various maximum aggregate size categories, with extrapolations to the entire A.T. For example, two of the 9% sample campsite clusters had an aggregate campsite size sum of greater than 20,000 ft^2, which suggests that there are about 22 such "mega-cluster" campsite locations on the entire A.T. Similarly, there are 9 10,000 ft^2 clusters (101 for the full A.T.) and 29 5,000 ft^2 clusters (324 for the full A.T.). Many of the larger clusters of campsites along the A.T. are associated with camping shelters; 55% of shelter clusters are greater than 5000 ft^2, and 18% of shelter clusters are greater than 10,000 ft^2.

Table 38. Number of campsites in the 9% sample and extrapolated estimates for the full A.T. by size (ft^2) of clusters.

Clustered Campsite Sizes (ft^2)	9% Sample (N)	Extrapolation Coefficient	Full A.T. Estimate (N)
All sizes	272	1 per 1.388 mi	3039
≥ 5,000	29	1 per 0.148 mi	324
≥ 8,000	18	1 per 0.092 mi	201
≥ 10,000	9	1 per 0.046 mi	101
≥ 15,000	4	1 per 0.020 mi	45
≥ 20,000	2	1 per 0.010 mi	22

The areal extent of impact influence on associated camping impacts is shown in Table 39, which presents results from non-parametric testing of count data for four campsite impact indicators across four categories of clustered campsite sizes. All tests were significant, with most of the change reflected in campsite clusters across the lower three categories, particularly between clusters above and below 5,000 ft^2.

Table 39. Environmental impacts associated with different categories of clustered campsite sizes.

Clustered Campsite Sizes (ft^2)		Access trails (#)		Damaged trees (#)		Fire Rings (#)		Stumps (#)	
	N	Median		Median		Median		Median	
<1,000	170	1	A	0	A	1	A	0	A
1,000-5,000	73	3	B	3	B	1	B	2	B
5,000-10,000	20	10.5	C	12	C	3	C	8	C
10,000+	9	27	C	17	C	5	C	29	C
Chi-Square/p-value[1]		97.9	<.0001	114.1	<.0001	92.1	<.0001	105.1	<.0001

1 – Non-parametric tests used for count data: Kruskal-Wallis one-way ANOVA test for significance with the Steel-Dwass test for multiple comparisons of median values.

The 10 Largest Mega-Clusters

This section examines the ten largest campsite "mega-clusters" from the 9% sample to further characterize resource impacts and the influence of site expansion vs. site proliferation. Mega-clusters are characterized by either large individual sites, numerous regular sites, or a combination of both. Table 42 ranks the ten largest mega-clusters and provides data on aggregate and median size, number of campsites and area name and location. A particularly noteworthy finding is that the aggregate size of these 10 mega-clusters represent 30% of total areal impact of overnight sites measured in this study (163,112 ft^2 of 539,939 ft^2). Mega-clusters tend to form in accessible unmanaged high use areas with relatively flat topography and a dependable water source. Flat terrain and unregulated camping allow both site expansion and proliferation to occur while extended periods of high camping demand during the thru-hiker "bubble" of use drives substantially higher demand for larger numbers of campsites at each overnight camping area. We note that the very high use White Mountains are absent from the mega-cluster list, which we suspect is attributable to a lack of flat terrain, professional management in the form of developed camping areas that include high-capacity huts and tent platforms, the particularly dense off-site spruce-fir forest growth, and the use of a voluntary group use registration system that effectively disperse groups in time and space.

Evidence of the large thru-hiker bubble effect on mega-cluster creation in SORO includes: 1) Each of the three 5k segments measured in Georgia have a mega-cluster in the top ten, 2) six of the ten are in the southernmost three A.T. states which receive the full effect of the intensive bubble of annual use (note that many hikers drop out or disperse in time and space as the bubble shifts further north), and 3) all other campsite clusters in GA are among the 20 largest mega-clusters. While seven of the ten largest mega-clusters include an A.T. shelter (Table 42) we attribute this to their inclusion on all maps and guidebooks where they serve as an additional "attraction" feature with water and toilet facilities; as a structure they are very effective at spatially concentrating the impacts of the individuals who actually camp within shelters.

Table 40 presents data on several associated campsite impacts for the ten largest mega-clusters. These findings indicate that the mega-clusters also account for considerable amounts of associated types of camping impact based on comparisons for aggregate impact from all overnight campsites and shelters. For example, the ten largest mega-clusters account for 34.7% of the stumps (340 of 979 recorded on all overnight sites) and 30.3% of all damaged trees.

Table 40. Associated campsite impacts for the ten largest campsite "mega-clusters" from the 9% A.T. sample.

Rank	Access Trails (#)	Damaged Trees (#)	Fire Rings (#)	Stumps (#)	Description
1	122	66	5	148	GA: Hawk Mtn Shelter
2	32	87	6	36	NC: Carter Gap Shelter
3	27	51	7	35	TN: Laurel Falls
4	22	16	15	29	PA: Antietam Shelter
5	35	17	5	3	GA: Low Gap Shelter
6	8	46	2	43	ME: A.T. intersection w/Jo Mary Rd.
7	9	14	2	24	MA: October Mtn. Shelter
8	29	12	6	5	GA: Tray Mtn Shelter
9	6	8	2	9	ME: Little Wilson Stream
10	13	4	3	8	TN: Walnut Mtn Shelter
Totals:	303/1132 26.8%	321/1060 30.3%	53/323 16.4%	340/979 34.7%	2nd value is total for all overnight sites, 3rd value is the percentage.

Table 41 presents data from four clusters of constructed side-hill campsites assessed in the 9% sample, providing an interesting contrast to data presented for the mega-clusters in Table 42. For example, as will be presented in the Discussion section, most of the campsites around the Hawk Mountain Shelter mega-cluster were closed and replaced by a new set of constructed side-hill campsites in 2016. This new area has 31 side-hill campsites with an aggregate size of 7,247 ft^2 but a median site size of only 227 ft^2. These data illustrate one possible response to addressing resource impacts at mega-clusters. Other options will be introduced in the Discussion section and described in an associated Best Management Practices document.

Table 41. Campsite clusters of constructed side-hill campsites with descriptive information.

Rank	Cluster Size (ft^2)	Campsites in Cluster (#)	Median Site Size (ft^2)	Description	GPS Coordinates
20	7,257	31	227	GA: Hawk Mtn Campground (new)	34.6659, -84.1477
28	5,575	6	623	NJ: Pochuck Mtn Shelter	41.2712, -74.5156
35	4,255	5	517	MA: Mark Neopel Shelter	42.6087, -73.1841
37	4,127	11	234	VA: Gravel Springs Hut	38.7637, -78.2339

To evaluate how campsite expansion and proliferation contribute to aggregate mega-cluster impacts let's examine the number and median sizes of campsites within the ten mega-cluster in Table 42. Site expansion appears to be the driving factor explaining three of these large mega-clusters (ranks 7, 9, and 10) given their large median sizes (3,306 to 5,013) and low numbers of sites (only 3). Site proliferation appears to be the driving factor explaining three of the mega-clusters (ranks 3, 5, and 6) given their small median sizes (576 to 1,182) and larger number of sites (7-10) (Table 42). The remaining clusters appear to have a mixture of large sites and numerous sites.

Table 42. The ten largest campsite "mega-clusters" from the 9% A.T. sample with associated descriptive information.

Rank	Cluster Size (ft^2)	Campsites in Cluster (#)	Median Site Size (ft^2)	Description	GPS Coordinates
1	31,390	11	2,711	GA: Hawk Mtn Shelter	34.6662, -84.1366
2	25,101	11	2,324	NC: Carter Gap Shelter	34.9995, -83.4944
3	19,740	10	705	TN: Laurel Falls (flat riparian area)	36.2653, -82.1231
4	15,482	7	1,518	PA: Antietam Shelter (flat riparian area)	39.7936, -77.4830
5	14,507	9	1,182	GA: Low Gap Shelter	34.7763, -83.8250
6	12,383	7	576	ME: A.T. intersection w/Jo Mary Rd.	45.6505, -69.0317
7	12,265	3	5,013	MA: October Mtn. Shelter	42.3552, -73.1543
8	11,443	6	1,355	GA: Tray Mtn Shelter	34.8039, -83.6771
9	10,843	3	3,306	ME: Little Wilson Stream (flat riparian area)	45.3761, -69.4689
10	9,958	3	3,478	TN: Walnut Mtn Shelter	35.8364, -82.9361

To further explore these relationships the largest 50 clusters were graphically portrayed with the aggregate area of the clusters on the y-axis, the number of sites per cluster on the x-axis, and the median size of the campsite clusters plotted by color in four size categories (Figure 28). Grouping A illustrates aggregate impact driven by site expansion as these clusters have only 1-3 sites that have a median site size of >2,000 ft^2. Grouping B illustrates aggregate impact driven by proliferation; these clusters have larger numbers of sites (6-31) that have median site sizes of <1,000 ft^2. Grouping C illustrates aggregate impact driven by both expansion and proliferation, with site numbers of 10-11 and median site sizes >1,000 ft^2.

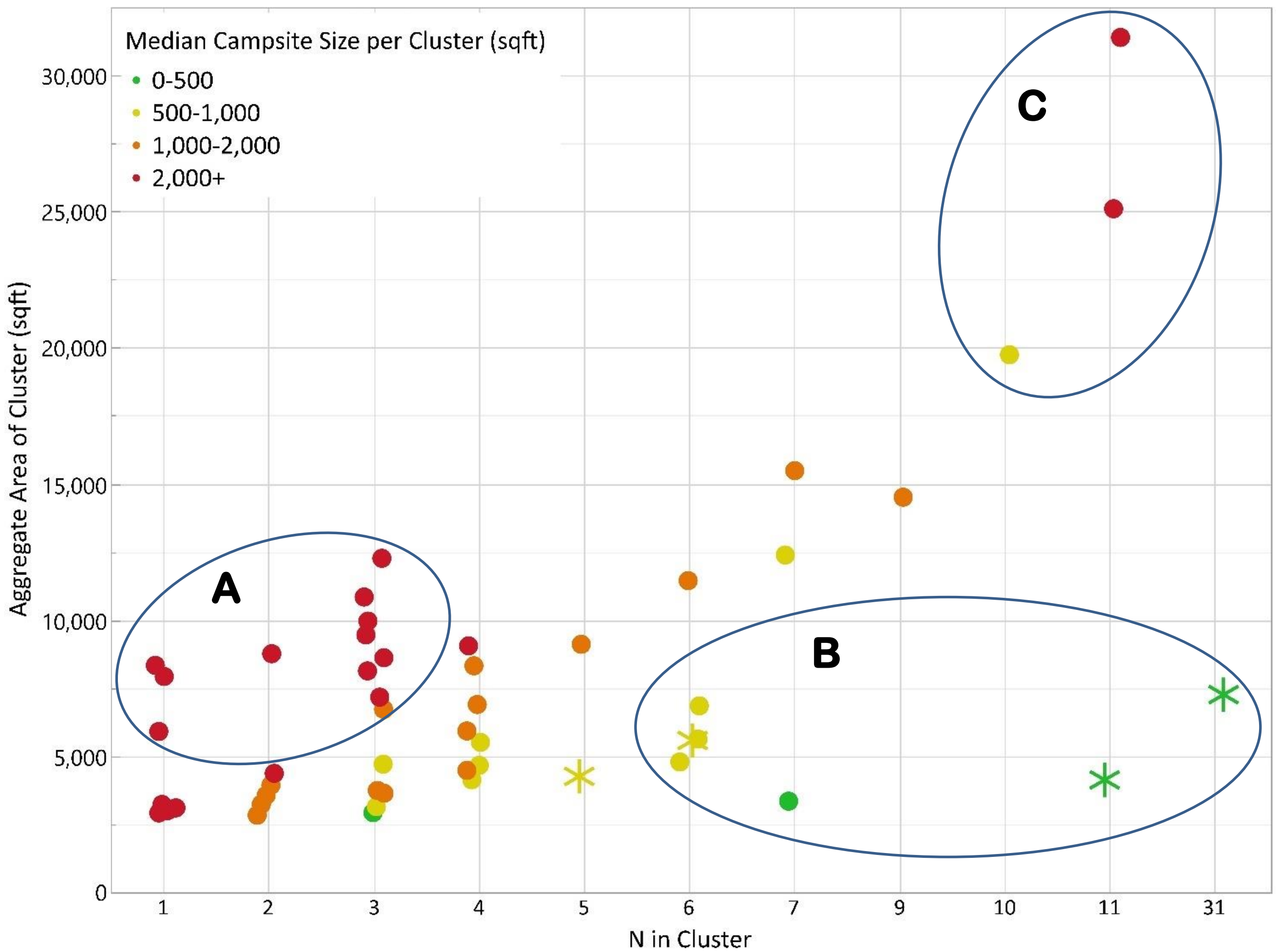


Figure 28. Aggregate area of cluster, number of campsites in cluster, and median campsite size per cluster (color-coded). Side-hill campsite clusters are shown as stars (*), all others as round points.

Hammock Camping Impacts

The 2019 annual survey of thru-hikers by the Trek.co (Mariposa 2020) found that 11.1% of thru- and section-hikers used a hammock as their primary shelter. As noted in the Methods, to investigate the potential impacts from this new and expanding form of camping we added additional indicators to our fieldwork in 2016 for the southern third of the A.T. Pairs of likely hammock tress 10-17 ft apart on and within 65 ft of site boundaries were examined and rated using a four-category condition class rating.

Field staff found only 13 occurrences of hammock damage among 362 surveyed campsites, 11 occurrences onsite and 2 offsite. All occurrences were rated class 2, minor damage. Hammock damage accounts for a total of 0.4% of total damaged trees onsite. Given that about 9% of long-distance hikers appear to be using hammocks regularly, our findings suggest that this new use is producing relatively little visible damage to trees. One possible concern is that adjacent off-site hammock camping could result in sufficient trampling of ground vegetation and organic litter that "satellite" sites of visible impact form and possible merge with campsites, further expanding their boundaries. Unfortunately, this could not be investigated, as satellite sites that field staff found and assessed could also have been created or used by tent and tarp campers.

High Elevation Visitor Use Impacts

In the NERO ATC region overnight and day use recreation site data for site size and area of vegetation loss from the sub-alpine zone (3,500-4,500 ft) and alpine zone (>4,500 ft) are compared to the low elevation zone (<3,600 ft) to examine high elevation visitor impacts (Table 43). In the sub-alpine zone, there were 6 recreation sites, including a shelter, a campsite, a resting/lunch site and 3 combination sties. While the shelter site was quite large (3,317 ft^2), the median site size for these 6 sites was only 274 ft^2 (mean = 786 ft^2), 62% of the median size of the low elevation recreation sites. The median area of vegetation loss was 107 ft^2, also 62% of the median value for low elevation sites (Table 43).

In the alpine zone there were 4 day-use recreation sites, including a vista site and 3 resting/lunch sites (Table 43). These sites were larger, the vista site was 1871 ft^2 and the median size of the resting/lunch sites was 500 ft^2 (mean = 790 ft^2). However, median and mean area of vegetation loss was quite small (75 ft^2 and 140 ft^2, respectively). Aggregate area of recreation site disturbance was greater in the sub-alpine zone (4,717 ft^2) than the alpine zone (3,159 ft^2), likely due to the large shelter site and somewhat larger site numbers (Table 44).

In this region trail maintainers often have signs asking visitors to remain on the A.T. and avoid off-trail traffic on sub-alpine and alpine vegetation. Scree-walls along some trail sections have also been applied, along with some rope fencing on Mt. Katahdin near Thoreau Spring. Monz et al. (2010) conducted research on high elevation visitor impacts in the northeast region and provide additional guidance.

Table 43. NERO data for overnight and day use recreation site numbers, site size, and area of vegetation loss for sub-alpine and alpine zones compared to low elevation areas.

Zone	Impact Indicators	Overnight Sites				Day Use Sites			All Sites
		Shelter	Campsite	Side-Hill Campsites	Road Campsites	Vista Sites	Resting and Lunch Sites	Combo Sites	
Low Elevation (<3600 ft)	**N**	**11**	**72**	**5**	**0**	**24**	**10**	**7**	**129**
	Site Size (ft^2)								
	Median	1892	352	445	n/a	688	200	1416	445
	Mean	2395	855	561	n/a	2275	298	1104	1209
	Range	536-7,924	37-7,097	154-1,463	n/a	26-16,190	51-1,106	110-2,197	26-16,190
	Vegetation Loss (ft^2)								
	Median	263	158	158	n/a	184	112	359	170
	Mean	787	396	161	n/a	1366	158	586	593
	Range	-568-4136	-44-4968	55-329	n/a	-523-9714	0-526	39-1295	-568-9714
Sub-Alpine (3600-4499 ft)	**N**	**1**	**1**	**0**	**0**	**0**	**1**	**3**	**6**
	Site Size (ft^2)								
	Median	3317	242	n/a	n/a	n/a	135	307	274
	Mean	3317	242	n/a	n/a	n/a	135	341	786
	Range	0	0	n/a	n/a	n/a	0	210-506	135-3317
	Vegetation Loss (ft^2)								
	Median	0	85	n/a	n/a	n/a	129	147	107
	Mean	0	85	n/a	n/a	n/a	129	184	128
	Range	0	0	n/a	n/a	n/a	0	-77-483	-77-483
Alpine Zone (>4500 ft)	**N**	**0**	**0**	**0**	**0**	**1**	**3**	**0**	**4**
	Site Size (ft^2)								
	Median	n/a	n/a	n/a	n/a	1871	500	n/a	582
	Mean	n/a	n/a	n/a	n/a	1871	429	n/a	790
	Range	n/a	n/a	n/a	n/a	0	125-664	n/a	125-1871
	Vegetation Loss (ft^2)								
	Median	n/a	n/a	n/a	n/a	0	149	n/a	75
	Mean	n/a	n/a	n/a	n/a	0	187	n/a	140
	Range	n/a	n/a	n/a	n/a	0	0-412	n/a	0-412

Table 44. Aggregate NERO recreation site size and area of vegetation loss in the sub-alpine and alpine zones with comparison to low elevation sites.

Zone	Aggregate Area of Disturbance	
	Site Size (ft^2)	Vegetation Loss (ft^2)
Low Elevation	155,994	76,455
Sub-Alpine	4,717	767
Alpine	3,159	561
All	163,869	77,784

DISCUSSION

Congress has mandated the NPS to protect the lands under its jurisdiction while also providing for visitation and recreation activities. Although public use and enjoyment is often a central purpose for creating and managing park lands, research has shown that even limited recreational activity can measurably alter natural resource conditions (Marion *et al.* 2016). These impacts must be balanced against the many personal and societal benefits that park visitation confer, including physical and mental health benefits associated with exercise and immersion in nature, and park and local community benefits from visitor expenditures, volunteerism and park stewardship support, and positive media exposure.

Recreation may endanger the goal of resource protection just as protecting resources may restrict opportunities for recreation. These apparently conflicting dual mandates present a management dilemma. Protected area stewards recognize the need for effective visitor management and resource protection programs to balance visitation with its associated resource impacts. The recurring question, "are we loving our parks to death?" increasingly challenges managers to assemble and implement policies, strategies, and actions that permit recreational activities within parks while continuing to maintain ecological and aesthetic integrity.

Land managers are charged with applying professional judgment in evaluating the type and extent of recreation-related impacts that may constitute unacceptable impact or impairment. This report provides useful data and analyses to partially inform such determinations while providing a quantitative basis for decisions to enhance management of visitors and resources to avoid or minimize recreation impacts. Research findings describe current conditions from a geographically representative sample and highlight some visitor impact management problems for the A.T. recreation infrastructure. Analyses and modeling conducted with the dataset also reveal useful knowledge that can be applied to correct these problems and enhance the sustainability of the entire A.T. tread and recreation sites.

A comprehensive summary of primary research findings is included in the Executive Summary section and is therefore omitted here. A table of A.T. infrastructure elements and their quantities and aggregate area of intensive visitor impact is included here to summarize the estimated aggregate area of impact associated with A.T. visitation (Table 45). These data reveal that 708 acres, 0.28% of the approximately 250,000-acre unit, are directly disturbed or impacted by visitor use. The largest percentage of impact (69%) is associated with the A.T. footpath, followed by overnight campsites (19%), ITs (6%), and day-use sites (5%).

Table 45. A.T. infrastructure component with quantities, aggregate area of intensive visitor impact, and percentage of total impact.

A.T. Infrastructure Component	Quantity[1]	Aggregate Area ft^2 (acres)	Percentage of Total (%)
Day-Use Sites	n = 2,356	1,513,646 (34.7)	4.91
Overnight Sites	n = 5,529	5,999,365 (137.7)	19.45
A.T. Trail Tread	2,190 mi	21,391,920 (491.1)	69.37
A.T. Informal Trails	255 mi	1,932,649 (44.4)	6.27
	Totals:	30,837,580 (708)	

1 – All quantities and aggregate areas are extrapolations from the 9% representative sample assessed in this study.

This section provides discussion about the research findings, including management implications and suggestions for corrective interventions. This study produced the most comprehensive and largest dataset developed within the recreation ecology field of study. All data are spatially related and describe baseline conditions for the A.T.

tread, ITs, and various types of day-use and overnight recreation sites. As the A.T. community implements Visitor Use Management planning and decision-making the dataset can be a core resource for selecting resource condition indicators, setting thresholds (standards) of quality, and developing/implementing monitoring protocols enabling periodic comparisons to past and desired future conditions.

Trail Management Strategies and Actions

Manage Visitor Use

The type, number, and behavior of visitors who travel trails can affect their condition and impacts. The A.T. is restricted to foot traffic except for a small section open to horses in Great Smoky Mountains National Park so type of use will not be considered for management alteration.

Regarding amount of use, consider that exceptionally large numbers of visitors could travel single file on the center of a highly sustainable and well-maintained tread in dry weather and produce negligible impacts to the tread. The amount of use is a consideration for managers concerned with social/experiential impacts, though generally only on exceptionally high-use A.T. segments (e.g., McAfee's Knob in VA) or non-sustainable segments that have not eroded to rock. The first management response is almost always to improve the sustainability of the trail by relocation or tread-shaping, hardening, drainage, or other maintenance. Accommodating exceptionally high use does require a wider "designed width" to allow for visitors to pass one another (Wimpey & Marion 2010), though unidirectional travel with looped configurations can reduce the need for passing and wider tread widths. For example, relocation to a side-hill alignment in steeper landform grades compels hikers to walk single file and ensures easy and effective tread drainage through grade reversals, water bars (knicks), dips, or tread out-sloping. Soil loss or displacement can be further reduced by limiting trail grade or adding steps, rock, or broken rock/gravel to augment tread substrates and armor the tread (Marion & Wimpey 2017, Parker 2004).

Accommodating exceptionally high use in flat terrain or through seasonally or perennially wet soils is considerably more challenging and may require hardened tread substrates, use of geosynthetic underlayments, bog bridging or boardwalks, turnpiking and the creation of raised treads and enhanced drainage with "lift and tilt" or borrow pit construction techniques, rock scree walls and low fencing, and other actions that limit trail width (e.g., placement of large border rocks (gargoyles) to center traffic or large logs arranged perpendicular to the trail with sections of a limited width removed) (Marion & Leung 2004). Since 69% of all A.T. visitor use impact is associated with the A.T. tread (Table 45), a strong management focus on limiting the width of the A.T. is warranted.

A few A.T. sections have even been paved to withstand exceptionally high use, for accessibility, or when the A.T. must traverse developed urban settings. Social/experiential considerations are likely to be the limiting factor in areas of exceptionally high use, and may require the limitation of use or redirection of use to alternative formal trails that meet visitor desires and shift the burden from the A.T.

Visitor behavior can also contribute to resource and social impacts. An educational messaging program (e.g., Leave No Trace) can encourage visitors to avoid popular A.T. sections and chose alternative trails, particularly during times of peak use or heavy rainfall/snowmelt. Similarly, visitors can be asked to walk single-file, pass others without stepping off-trail, and take breaks off-trail only on resistant/durable surfaces. Messaging can also ask visitors to not cut switchbacks and restrict their traffic to the A.T., blue-blazed side-trails or well-established ITs. In areas with rare species or sensitive high-elevation plant communities, education can direct visitors to remain on the formal A.T. and avoid off-trail traffic. Similarly, social/experiential concerns can be addressed through educational messaging, such as asking visitors to hike separately in smaller groups, remove their trash and dropped food, and to be courteous to other hikers (e.g., not play music on external speakers). Regulations are rarely necessary but are an option when educational and site management actions fail to achieve desired or mandated resource or social conditions. Relevant regulations include rationing or limits on visitor numbers, group size limits, type of use restrictions, and prohibitions from feeding wildlife or off-trail travel.

Trail Location and Design

A sustainable trail is designed, constructed, and managed to accommodate the intended types, amounts, and seasons of use to provide high quality visitor experiences while protecting the trail infrastructure and adjacent natural resources. Many current problems can be traced to the original A.T. layout in 1923-37 that had little regard for or awareness of modern sustainable trail design knowledge. While most of the A.T. has been relocated and reconstructed since that time there remain many older and some newer segments for which relocation will be the preferred management response to unacceptable resource impacts.

The Literature Review section of this report provides descriptive information about the three core trail impacts (trail soil loss, widening, and muddiness) and the primary factors that influence them. The most important attributes are a trail's layout and orientation relative to topography. Side-hill trails in terrain with landform grades of 30-50% are the most sustainable; steep trails oriented close to the fall line or trails in flat terrain, particularly in wet soils, are the least sustainable. Additional guidance is provided in trail management books (Demrow & Salisbury 1998, IMBA 2004, 2007, Hesselbarth et al. 2007, Parker 2004) and trail science publications (Marion and Leung 2004, Marion & Wimpey 2017, Meadema et al. 2020, Wimpey & Marion 2010).

A trail sustainability index based on trail grade and slope alignment angle was applied to the A.T. in this study (Table 8, Table 9) and we suggest it may be helpful to apply it in future surveys and problem analyses to identify the least sustainable sections based on those metrics. Additional analyses with trail grade and landform grade (Table 11, Table 19, Figure 18) also yielded findings of interest, such as the greater importance of TSA and avoiding fall-line trails in steeper terrain and ensuring adequate water drainage along low gradient trail treads. These types of analyses will be more accurate in areas where LiDAR-derived topographic data are available. An advantage is that it's an easily applied standardized index that could assist in quantifying the sustainability of the A.T.'s layout and design. A limitation is that some to many of the A.T. segments identified as "unsustainable" have already eroded to rock or have been armored (i.e. rockwork or staircase development) or have had bog bridging installed. Ground truthing will be necessary to verify and augment quantitative GIS assessments of grade and alignment.

Such analyses would yield comparable data for the ATC management regions and/or the A.T. VUM zones that could assist in decision-making regarding budgets and staffing for trail relocations or corrective tread hardening. In general, relocations are preferred over enhanced tread maintenance when a long-term, say >100+ year, time horizon is applied. Relocations almost always involve constructing longer replacement treads through adjacent terrain, but over time aggregate impact and maintenance efforts on these new sustainable treads will be substantially less than had the original tread been retained. Trail professionals and scientists know this to be true, park and forest botanists and wildlife professionals often require scientific studies to be convinced (see Marion & Wimpey 2017, Olive & Marion 2009, Parker 2004, Tomczyk et al. 2016, Wimpey & Marion 2010).

Trail Construction and Maintenance

The protected A.T. corridor has a limited width in many areas so relocations to more sustainable alignments are not always a viable option. Alignment deficiencies must sometimes be addressed through enhanced construction practices, such as the use of rock steps and stone staircases, tread armoring with rock, bog bridging and boardwalks, geosynthetics, or augmenting tread substrates with gravel/soil mixtures (Monlux & Vachowski 2000, Steinholtz & Vachowski 2001). To avoid excessive soil loss most trail construction guidance recommends keeping trail grades below 10-12% (Hooper 1988, IMBA 2007, Hesselbarth et al. 2007). Statistical modeling by Dissmeyer and Foster (1984) reveals that soil erosion rates become exponentially greater with increasing trail grades, particularly above 10%. These findings are explained by the greater velocity and erosivity of running water on steep slopes and by increased soil displacement by user forces (IMBA 2007, Leung & Marion 1996).

In steeper terrain, construction and maintenance practices can help to minimize soil loss by hardening the tread with well-anchored rock in the form of steps or tread armoring (Figure 29). Large embedded rock is resistant to displacement by traffic and water runoff and such treads can often retain out-sloped profiles under heavy use. However, frost heaving during wintertime freeze-thaw cycles can degrade the integrity of stonework over longer periods of time. Use of broken angular rock/gravel mixed with soil can be effective on lower gradient segments of trail, or combined with other armoring techniques. On steep trail segments such materials may be displaced downhill by traffic or water. Geotextile three-dimensional web or cellular containment products are also less effective, as any overlying tread substrates are likely to displace quickly, exposing the upper portions of these plastic containment products to UV radiation, which accelerates their breakdown (Monlux & Vachowski 2000) (Figure 30A). These products are costly, unnatural and tend to "float" up through soil and rock over time under all but perfect installation and conditions.

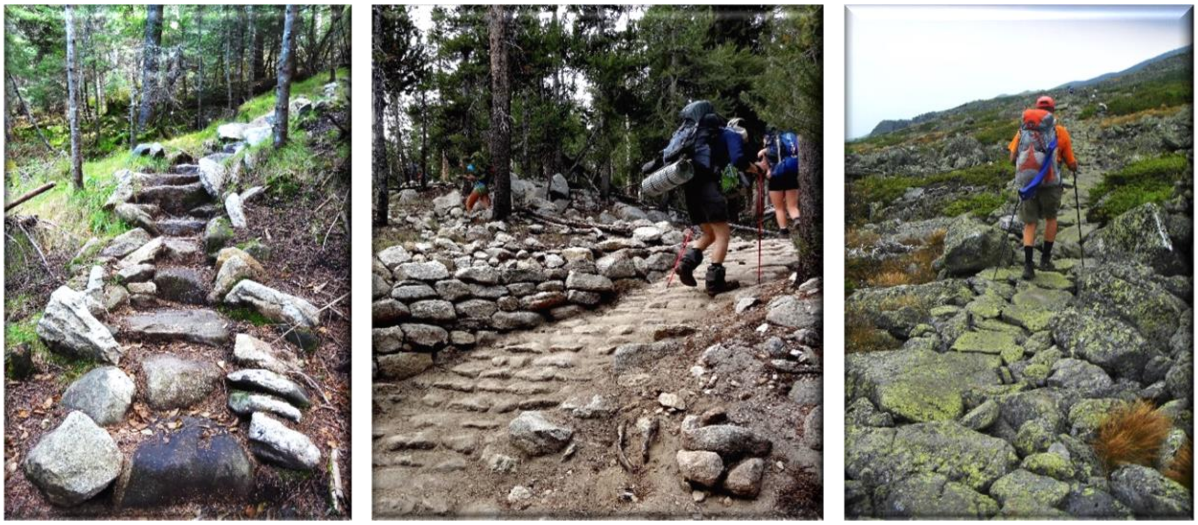


Figure 29. Tread construction with stone steps or stone armoring of trail treads can help minimize soil loss in steep terrain.

Figure 30. Cellular geotextile products (A) can retain soils within their 3-D cells but fill material placed on top will erode or displace downhill, exposing it to traffic and UV-radiation that breaks down the plastic. Its efficacy is higher in flat terrain and wet soils. Rock borders and scree walls (B) can be an effective practice for centering traffic and deterring off-trail travel.

If flatter terrain, construction and maintenance practices can help to minimize tread muddiness and excessive widening. The challenges here are that the lack of topography allows lateral traffic so if the intended tread develops exposed roots or rocks, ruts, or muddiness, hikers will shift their traffic to smoother/drier off-trail routes. Soil loss can be prevented by ensuring an adequate density of well-maintained tread drainage features. Hikers can be encouraged to stay on the intended treads by improving their condition or by adding off-trail rugosity and barriers, such as placing large gargoyle rocks just off-trail, removing only narrow sections of downed trees that cross the trail, adding trail borders of rocks or scree-walls, and managing off-trail woody vegetation to form a barrier (Figure 30B).

Eroded treads with substantial rock or root exposure can be addressed by adding soil from uphill side-slopes or borrow pits, preferably mixed with broken rock/gravel. In the absence of rock, geosynthetic cellular containment products can be effective only under ideal installation and site conditions, e.g., in flat terrain where they will retain overburden and remain hidden (Meyer 2002). These products can be filled with any type of soil, but drainage is improved when substrates have a larger percentage of coarse material. A wide variety of geosynthetic products have been developed, often for use in wet soils and to support trail or even vehicular traffic (Monlux & Vachowski 2000).

A variety of tread construction practices have been devised for trails crossing flat terrain with persistently wet soils or flooding, including the construction of parallel trailside drainage ditches and development of raised tread turnpikes (Forest Service 1984, 1991). Bog-bridging can also elevate the trail on single or double boards or logs that are supported by stringers at each end (Figure 31A). When water levels vary substantially, boardwalks or puncheons are necessary, consisting of more elaborate raised walkways with decking. These can be constructed of wood, plastic, or even metal when longer spans are necessary, or where fire is a common hazard.

Trail maintenance actions can also improve the sustainability of treads through effective tread drainage and vegetation management practices. Managing surface water so that trails avoid intercepting, concentrating, and transporting water along their treads is perhaps the most important goal. Unlike forest roads, trails rarely rely on crowning or trail in-sloping with drainage ditches along their upslope sides due to the larger maintenance effort of clearing debris and soils from the ditches and periodically passing the water under or across the trail through culverts or french drains (Birchard & Proudman 2000, Parker 2004). Managers more commonly out-slope treads to the down-hill side 2-3% and remove water with short grade-reversals of the tread (preferred), drainage dips, or rock/wood armored water bars (Birchard & Proudman 2000, Marion & Leung 2004, Hesselbarth et al. 2007) (Figure 31B&C). All tread shapes constructed to shed water rarely maintain their constructed profiles over time: tread compaction, soil displacement from traffic, soil erosion, and the development of a berm along the lower trail edge eventually act to keep water on the trail (Marion & Wimpey 2017, Parker 2004). This underscores the need for matching the frequency of tread drainage features to trail grade and substrate erosivity (Parker 2004, Forest Service 1991) and for ensuring periodic tread drainage maintenance.

This study was unable to include evaluations of the efficacy of tread drainage features but a trail survey in Great Smokey Mountains National Park assessed 4137 drainage dips and 3804 water bars, finding that only 20% of the unarmored drainage dips were judged to be “very effective” in removing water from treads vs. 44% of rock or wood armored water bars (Marion 1994). These findings suggest that neither type of feature remains effective unless trail maintainers keep them clean of built-up organic debris and eroded soil, and that the armored features retain their efficacy for longer periods. An Australian study found that 87% of water bars were judged to be in good condition but only 13% were judged to be very effective in removing water from treads, suggesting improper and/or unskilled installation (Mende & Newsome 2006). Our informal observations along the A.T. support both these findings, with field staff emphasizing insufficient densities of tread drainage features in steeper terrain and poor maintenance of these features as the most common contributor to tread soil loss and muddiness.

These findings reinforce the most sustainable practice of using tread grade reversals (Figure 31C) to remove water from treads. Designing or reconfiguring trails that periodically reverse tread grades, known variously as rolling contour trail alignments, terrain dips, rolling grade dips, or simply grade reversals, represent the “Best

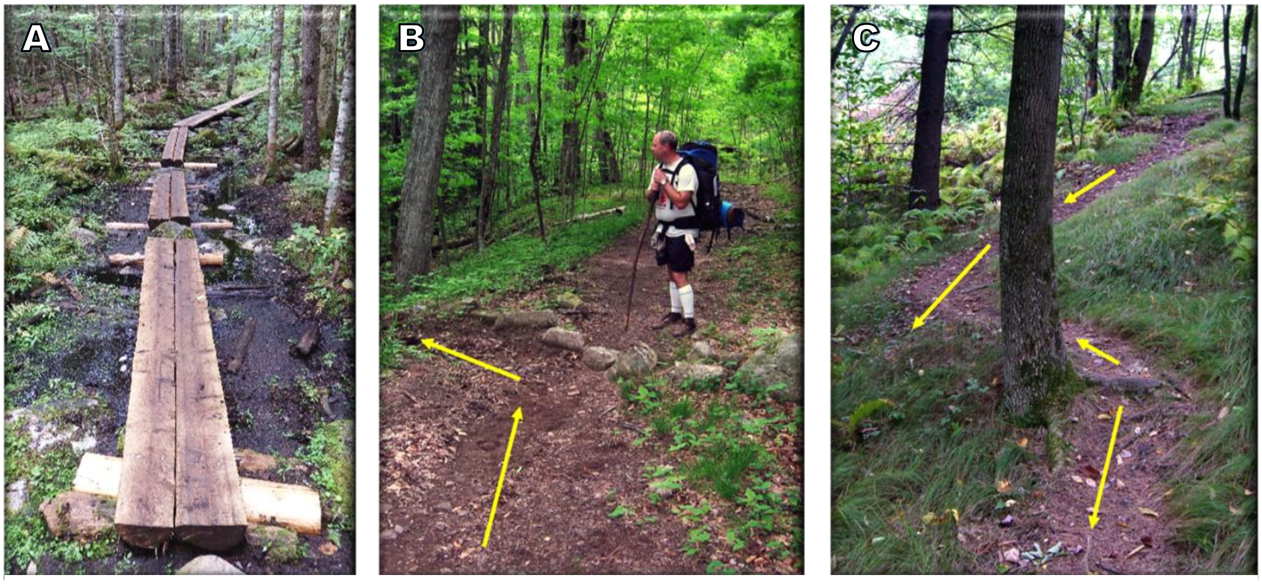


Figure 31. Bog-bridging (A) is an effective practice for raising the tread above wet soils. Rock or wood water bars (knicks) (B) remove water from treads but must be maintained annually to remain effective. Grade reversals of the entire tread (C) will always remove all water and require little to no maintenance.

Management Practice" for removing water from trails. When the entire tread briefly reverses grade all water is forced off the trail and little to no maintenance is necessary to preserve their efficacy over time (IMBA 2004, 2007, Parker 2004, Marion & Wimpey 2017). Locating these reversals appropriately presents a similar challenge to the water bar installation dilemma, with significant effort and experience yielding better results and placement.

Finally, trail maintainers can encourage visitors to remain on trails by managing trailside vegetation. Woody vegetation can be trimmed over time to provide an effective barrier in many forested vegetation types. Generally, for a two-foot hiking trail the width of vegetation trimming should be about four feet, though this can be narrowed to "center" traffic on a trail and deter tread widening. In open areas, taller non-woody vegetation can often be trimmed to center traffic, though visitors can more easily walk through grasses when motivated to circumvent tread obstacles our muddiness. Greater reliance on trailside rockwork or scree walls is necessary in open areas like alpine zones that lack topography or vegetation to deter off-trail travel. When ineffective, such trails should be relocated to side-hill alignments in steep terrain whenever possible.

Additional discussion of the A.T. tread condition findings and further analyses of factors that influence trail impacts can be found in Meadema et al. 2020.

Informal Trail Management

The development, deterioration and proliferation of visitor-created informal trails in protected areas can be a vexing management issue for land managers. Formal trail systems often fail to provide access to all locations required by visitors seeking to engage in a variety of appropriate recreational activities. Traveling off-trail is necessary to engage in activities such as taking rest breaks, enjoying vistas, nature study, fishing, or camping. Unfortunately, research and management experience reveal that ITs frequently have unsustainable attributes, including steep grades and fall-line routings parallel to the landform slope (Wimpey & Marion 2011). Such alignments are rarely sustainable under heavy traffic and subsequent resource degradation is often severe. Large IT networks can degrade vegetation, organic litter and soil, displace wildlife, alter hydrology, degrade habitats, spread invasive species, and fragment landscapes. Creation of multiple routes to common destinations is another frequent problem, resulting in "avoidable" impacts such as unnecessary vegetation/soil loss and additional fragmentation of flora/fauna habitats.

IT management concerns can be incorporated into VUM planning and decision-making by including one or more indicators related to IT formation and impacts. The simplest indicator would be aggregate length or area of ITs per sampled area (like a 5 km segment); the aggregate length or area of ITs within higher condition classes or width categories could also be included to incorporate IT conditions. Monitoring methods could be adapted from those employed in this study (Appendix 1). A problem analysis process (see separate final report: Sustainable Camping "Best Management Practices") can be applied to evaluate IT problems, consider a range of alternative management interventions, and select one or more corrective actions to implement. Subsequent monitoring to evaluate the efficacy of implemented actions as part of an adaptive management process can then feed back into another round of problem analysis if unacceptable conditions persist.

Four general strategies for managing ITs include:

1) **Improve management of formal trails.** The A.T. tread should be well-marked, well-maintained, and useable so that visitors will choose to follow it.
2) **Ignore or formalize informal trails.** Some ITs have acceptable design attributes and access locations, such as vistas, campsites, or water that they can be left open for continued visitor use. These ITs serve an important resource protection function by concentrating visitor traffic on a narrow tread and protecting adjacent vegetation from trampling damage. These trails have or could be formally adopted as "blue-blazed" side-trails and included in annual maintenance work to relocate non-sustainable sections, trim vegetation, and drain/harden their treads.
3) **Close and restore unacceptable trails.** Informal trails with non-sustainable design attributes, trails that threaten sensitive resources, or unnecessary trails with duplicative routings can be closed and rehabilitated. Recognize that successful trail closures and restoration require substantial and sustained management effort. The principal reason for low success rates is that while trampling impacts occur rapidly with low levels of use, vegetative and soil recovery occurs very slowly, and complete recovery is prevented unless nearly all traffic is removed from treads for several years. Note that studies have been conducted to develop improved guidance for educational and site management actions to close ITs and protect rare species or sensitive high elevation vegetation (Hockett et al. 2010, Park et al. 2008).

Recreation Site Management Strategies and Actions

A separate component to this final report titled: Sustainable Camping "Best Management Practices" (hereafter referred to as the "BMP report") was developed to provide easy access to guidance on the best available management strategies and actions found by researchers and managers to be effective in minimizing camping resource and social impacts. It is intended to serve as a reference document or "toolbox" describing a wide array of site management, educational, and regulatory "tools" and practices to aid managers and volunteers.

Land managers follow a containment strategy when managing infrastructure components that support travel by providing formal trails, such as the A.T. tread. Visitors are encouraged to use formal trails when possible, which are sustainably designed, constructed, and maintained to accommodate intensive long-term foot traffic. In contrast, land managers have generally not used a containment strategy for overnight visitation (shelters excepted), most often allowing visitors to select and create their own campsites, which account for 24% of the areal extend of A.T. visitor impact. Studies and monitoring data have consistently found that visitors create substantially greater numbers of campsites than are necessary and that most sites are in flatter terrain that offer no resistance to campsite expansion or proliferation.

This study found that unconfined (unregulated) camping along the A.T., particularly in the southern states, has led to the creation of many "mega-clusters" of campsites that have developed from a combination of site proliferation and expansion. For example, analyses of the ten largest mega-clusters of campsites revealed that they account for 30% of the aggregate areal extent of impact from all overnight sites and many of the associated impacts to trees and other attributes. Six of the ten largest mega-clusters were in the southernmost A.T. states and the area of camping disturbance for SORO (44 ft^2/acre) was more than twice as much as any other ATC region. Both findings are largely attributable to the large A.T. annual bubble of use and its substantial demands for large numbers of campsites at each overnight destination.

The A.T. community has long recognized and sought to resolve the camping impact management problems in the southern states associated with the thru-hiker bubble of use. Visitor use data reveal that the number of thru-hikers has increased from about 1,100 in 2006 to 3,000 in 2015 (Hollis 2015). Available 2015 data collected on the busiest days at Springer Mountain characterize the composition of the thru-hiker bubble as having approximately 70 thru-hikers, 45 section-hikers, and 85 other day-use and short-term overnight visitors. Efforts to encourage flip-flop hikes with mid-trail starting points and to flatten the bubble through a voluntary thru-hiker registration system have helped but not yet resolved overuse problems in the southern states. Data from this study document the substantial numbers and sizes of campsites and other impacts associated with the thru-hiker bubble, particularly the development of large mega-clusters of campsites which also degrade social conditions. Even very limited use during the rest of the year will prevent resource recovery on most campsites due to low recovery rates. These impacts are largely driven by the exceptionally large numbers of campers that must be accommodated each night as the bubble of use slowly moves north each spring. Larger organized groups and loosely affiliated but large "groups" of thru-hikers (e.g., "trail families") that are unwilling to split and camp separately can also significantly expand campsites.

Study results support the need to further flatten the thru-hiker bubble to reduce and redistribute the number of overnight campers. Options include shifting section-hikers to other seasons, discouraging former thru-hikers from returning to hike with the new thru-hikers, and encouraging short-term (weekend) backpackers to avoid the A.T. during these peak use periods. A regulatory approach with use rationing and daily start limits is also an option if other actions are ineffective. These resource and social impacts are expected to persist and may worsen unless effective management actions are implemented. The new VUM framework can aid in addressing these problems, with indicators and thresholds (standards) reflecting the limits of acceptable resource and social/experiential impacts, and subsequent monitoring to evaluate management success in minimizing these impacts.

Site Management Options

A.T. camping shelters do attract and spatially concentrate camping activities to their small "footprint" of impact and immediately adjacent areas. While many view A.T. shelters as "visitor convenience" facilities they also act as an effective resource protection facility by limiting the areal extent of camping impact *for those who sleep within them*. Though rarely investigated, camping shelters and huts excel in spatially concentrating camping activities to the structure's small footprint (Marion & Leung 1997). A study of camping impacts at Great Smoky Mountains National Park found that AT shelters accommodated 37% of the backcountry overnight visitation while including only 10% of the total area of backcountry camping disturbance (Marion & Leung 1997). This finding is even more compelling given that their data was also confounded by the inclusion of shelter-associated tent camping areas.

However, data also reveal that the shelters' dependable water sources and inclusion on all maps, guidebooks, and phone apps make them a popular destination for tent and hammock campers, leading to the creation of high densities of surrounding campsites and problems with site expansion, proliferation, and visitor crowding and conflict. For example, seven of the ten largest A.T. mega-cluster campsites surround shelters. Furthermore, A.T. overnight camping guidance stresses that visitors should not depend on shelters, and their numbers and capacities have been largely fixed in the last 20 years as overnight use continued to increase. Building additional shelters and increasing their sizes is not consistent with the desired A.T. Trail Experience and associated management policies (see report section titled "*Appalachian Trail Conference Guidance*"). Based on a 1999 visitor survey, about 43% of non-thru hiking campers use shelters and 59% of thru-hikers use shelters, with an additional 12% of non-thru hikers and 14% of thru-hikers camping in areas around shelters (Manning et al. 2000). Relocating shelters to sloping or rocky areas that spatially concentrate camping activities could be key to limiting areal impacts associated with nearby tent camping, along with matching supply and demand and efforts to shift more tent camping to locations away from shelters.

Studies have also demonstrated the efficacy of constructing tent pads with wood or rock borders, including in flat terrain. Dixon and Hawes (2015) describe how the construction of camping platforms in the alpine zone of the Arthur Range of Tasmania "successfully focused camping pressure and so constrained or limited impacts." Similarly, a longitudinal study of the popular Overland Track in Tasmania by Dixon (2017) found improved conditions at locations where wooden camping platforms had been installed, with track rangers reporting a greater concentration of camping use after the structures were installed. While similar wooden camping platforms have been constructed in the New England states, we highlight the advantages of soil tent pads outlined by wood or rock borders that allow tents to be staked in soil. This also indicates that the most effective actions managers can apply to reduce impact in popular high use camping areas are those that increase the spatial concentration of camping activity, like the installation of shelters or tent pads when camping must be accommodated in flat terrain.

These findings collectively point to a strong management need for increasing the sustainability of tent camping along the A.T., which has an estimated 5,529 campsites. The BMP final report characterizes a range of management options for addressing the need for more sustainable campsites, but several are highlighted here.

Site Expansion Potential – Various ground-based and GIS methods for evaluating this attribute have been developed but they all seek to identify small relatively flat campsites/tent pads surrounded by terrain that is either too steep (>15% grade) or too rocky and uneven to allow site expansion or proliferation. Dense woody vegetation is not a reliable attribute as it can be eliminated by visitors, fires, or insects/disease over time.

Current Campsite Size - While 56% of the sampled campsites are <500 ft^2, 25% are >1000 ft^2 and 13% are >2000 ft^2 (termed mega-sites) (Figure 25). Replacing the larger campsites with more sustainable expansion-resistant campsites is a suggested practice to reduce the aggregate area of camping impact.

Site Occupancy Rates – Ridgerunners and possibly volunteers could conduct campsite occupancy surveys in problem areas for a sample of 10-12 nights stratified by weekend/weekday, and within/outside of the thru-hiker bubble to provide information for decision-making about campsite numbers. This requires mapped campsite locations with unique site numbers and evening or morning visits to tally number of tents or campers. Low occupancy rates (<25%) indicate an over-supply of campsites and "avoidable" visitor impact, as compared to a smaller number of sustainable frequently used campsites.

Additional Considerations – Many other factors should be considered, as described in this report and the affiliated BMP report. These include distance to the AT, water, other sites, and rare species or sensitive habitats, number/quality of tent sites, forest cover/grasses, hazard tree threats, and attractiveness to visitors.

Implications from Relational Analyses

Extensive regression modeling performed as part of this research (see Arredondo et al. 2020) revealed that managers can use macro- and micro-topography to effectively constrain a campsite's ability to expand. This is similar to side-hill trail alignments, where steep side-slopes act to concentrate traffic on a narrow tread (Wimpey & Marion 2010). Perhaps the most important finding of this study is that campsites located in sloping terrain will spatially concentrate camping activities to the available flat terrain, effectively constraining site expansion when offsite areas are sufficiently steep. The best campsite size predictor yielded by our modeling was the percent of 33 ft wide "doughnut" buffers around a campsite occupied by greater than 15% slopes. The implication of this finding is that spatial concentration of camping activities is highest when a campsite is completely surrounded by steep terrain. Both "naturally-occurring" and constructed side-hill campsites in terrain with >15% slopes provide the most sustainable campsites for intensive long-term use; current and ongoing research is developing protocols for locating these campsites within trail corridors using ground-based and GIS surveys.

Regression modeling and supporting trail widening analyses (Wimpey & Marion 2010) also demonstrate the significant influence of micro-topography, which we term rugosity, in constraining campsite size expansion. Topographic roughness from excessive rock, roots, or uneven ground sufficient to deter tenting also constrains and spatially concentrates camping activities. For example, the management strategy of "ice-berging" rocks is a traditional practice of partially burying large rocks to increase topographic roughness to close a campsite or constrain activity to a reduced portion of a campsite (Marion 2003). This practice is impractical in large flat areas as it may merely move camping impact to adjacent flat areas. Unfortunately our exploratory analyses in this study revealed that GIS micro-topography measurements using 1 to 3 m DEM data were apparently insufficiently sensitive measures of rugosity (Brubaker et al. 2013), but our field-assessed categorical measure showed greater promise. Further research on this attribute is recommended.

Small naturally-occurring or constructed side-hill campsites also effectively limit other forms of camping impact, such as the number of fire sites, damaged or felled trees, and soil loss. In comparison to normal or large campsites, side-hill sites have exceptionally few onsite or adjacent trees that managers may need to survey and remove as hazardous trees. To enhance experiential qualities, reducing crowding, conflicts, and noise, managers can physically separate side-hill sites (e.g., >200 ft apart) (Daniels & Marion 2006). An important advantage of relying on macro- and micro-topography to spatially concentrate camping activities and constrain campsite expansion is that once visitors are on the site they are simply interacting with the natural environment, which effectively compels their behaviors. Visitors simply cannot erect a comfortable tent in sloping, rocky, or uneven terrain. This is viewed as more natural and effective than compelling similar behaviors through regulations (e.g., visitors must camp within 20 ft of a fixed camping post or fire ring). Similarly, a reliance on education and low impact practices (e.g., please camp in the already barren central core campsite areas) is only effective when visitors are fully aware of and compliant with such voluntary practices (Marion 2014, Marion & Reid 2007).

Regression modeling (Arredondo et al. 2020) also revealed a positive and significant relationship between area of vegetation loss on campsites and their tree canopy cover. Sunny campsites with tree cover <5% have the smallest area of vegetation loss and the greatest vegetation cover. Campsites with intermediate tree cover of 25-50% experience the greatest area of vegetation loss with intermediate vegetation cover. Shaded campsites with tree cover >75% have lost most of their vegetation cover and retain only sparse cover in peripheral areas. What explains these relationships is the differential variability in the trampling resistance and resilience (ability to recover) of grasses vs. broad-leaved herbs. Experimental trampling studies consistently reveal that grasses and sedges are highly resistant and resilient to trampling in sunny meadows and somewhat less so in open forests; however, they are intolerant of shade and provide little cover under full tree canopies (Cole 1995, Hill and Pickering 2009). In contrast, herbs, which have low resistance and resilience to trampling, reach their greatest cover in forests with 25-50% canopy cover and also decline to limited cover under dense forest canopies.

The implications of these relationships are that grassy meadows and open forests provide exceptionally sustainable locations for dispersed pristine site camping or for locating established or designated campsites. An experimental camping study by Cole and Monz (2003) in the Wind River Mountains of Wyoming found that meadow campsites resisted trampling damage and recovered significantly faster than identical camping activity in settings with forest canopies. Similarly, Eagleston and Marion (2017) reported that tree loss over 32 years on Boundary Waters Canoe Area Wilderness campsites resulted in increased sunlight and significant increases in the percent and areal extent of vegetation cover, primarily trampling-resistant grasses and sedges, which significantly reduced measures of exposed soil. Finally, we note that forests with particularly dense canopies can also make good locations for dispersed and established/designated site camping because they have very limited vegetative groundcover that can be lost. A disadvantage is their greater potential for hazardous trees and related safety concerns.

Forested campsites that lose most of their trees with time and are colonized largely by grasses are ecologically and aesthetically different than the original landscape, "unnatural" changes that could reduce a visitor's perception of wilderness and wilderness character (Eagleston & Marion 2017, Eagleston & Marion 2018). Shifting camping to more open forests and meadows could alleviate these concerns and reduce safety threats to visitors from camping near hazardous or dead trees.

While it is possible to apply the criteria yielded by these regression analyses in selecting more sustainable campsite locations there remains two fundamental challenges, the need to: 1) clearly distinguish sustainable sites from less sustainable sites, and 2) motivate visitors to find and use sustainable sites. The campsite use-impact relationship reviewed in the BMP report suggests that aggregate camping impact could be substantially reduced by either employing a pure dispersal strategy with pristine site camping in low use areas, or a containment strategy with established or designated site camping in moderate to high use areas (Leung & Marion 2004, Marion 2016a Marion et al. 2018a). Both strategies rely heavily on the ability to select sustainable sites that can accommodate camping activity with low per capita resource impact. Designated site camping requires campers to use only those sites, while established site camping seeks to select or create and identify the most sustainable campsites and encourage their use. Unfortunately, A.T. managers and volunteers currently allow unconfined (unregulated) camping along most of the A.T. and have applied little control over campsite locations.

We suggest greater experimentation in the A.T. community with both dispersal and containment strategies. Sustainable established campsites could be selected from existing campsites or identified and created, marked for visitors by a distinctive triangular paint blaze, and included in phone apps so that visitors can find and use them. In particularly popular high-use areas camping could be restricted to the most sustainable designated campsites, which could be identified by signs or anchored steel fire rings and included in guidebooks and phone apps. Greater efforts focused on identifying and closing the least sustainable campsites, with site restoration/recovery work, would also be beneficial. Another option noted in the BMP report is to work with state wildlife management staff to use meadows created for improving wildlife habitat for overflow camping during peak use periods. Additional meadows could even be strategically created in areas adjacent to the A.T.

A continued emphasis and expansion of low impact Leave No Trace educational messaging and courses is also supported by this research. Many A.T. visitors return for recurring trips so educational efforts that encourage adoption of low impact practices have the potential to significantly reduce visitor impacts (Marion & Reid 2007). Pressing issues include campsite selection, spatially concentrating camping activities on durable surfaces, food storage, and human waste grey-water disposal practices. Long distance hikers are the best candidates for further experimentation with dispersed pristine site camping, particularly when hikers are not traveling with groups. However, such practices cannot easily be taught until hikers have mastered the more rudimentary camping and low impact practices. Perhaps focused presentations at the Damascus Trail Days event on more advanced LNT skills like pristine site and hammock camping (see below) could be effective.

A final option is to promote low-impact hammock camping, which has already increased to approximately 11% of long-distance A.T. backpackers. Field staff found only 13 minor occurrences of visually obvious tree bark damage attributed to hammock camping, representing 0.4% of the assessed onsite tree damage. This suggests that at current levels of hammock camping there should be little concern for tree-related impacts. Nevertheless, promoting low impact practices, such as substituting wide webbing for ropes or narrow straps, is suggested (see Marion 2016b). Our assessments were unable to distinguish hammock-related trampling of ground vegetation and organic litter from that associated with tent or tarp camping, so the concern that adjacent off-site hammock camping spots could enlarge and merge with campsite boundaries to expand the areal extent of camping impact remains a concern that requires further investigation.

We note some important "low-impact" advantages from using hammocks: 1) substantially reduced ground-contact and vegetation trampling or substrate compression associated with tents and tarps, 2) ability to camp in sloping terrain or over portions of campsites that are less desirable for tents/tarps, 3) no/little need to remove vegetation, sticks, and rocks, and 4) greatly facilitates the ease/efficacy of dispersed pristine site camping. Marion (2016b) provides additional information on hammock camping, including many low impact practices. We conclude that hammock camping likely has substantially greater advantages than disadvantages and suggest that this form of camping should be promoted to reduce camping impacts. To avoid tree impact and site expansion impacts A.T. stewards could install hammock posts or even hammock circles of posts (accommodating 4-8 hammocks) in areas where higher camping capacities must be accommodated. Continued monitoring of hammock impacts is also recommended.

Monitor Trail and Campsite Conditions

The capability to inventory and monitor the conditions of trails and campsites altered by recreation use is essential to effective management decision-making. Monitoring can be defined as the systematic collection and analysis of data at regular intervals, in perpetuity (USD1 2001). As with other prominent and critical resource issues, managers cannot afford a wait-and-see attitude or rely upon subjective impressions of deteriorating resource conditions. When establishing policy for backcountry management, such data describe the condition of trails and campsites, relationships between biophysical and use-related attributes, and the likely effects that visitor activities have on biophysical, social, and managerial environments. These relationships are complex and not always intuitive. A reliable information base, therefore, is helpful for managers who seek to develop and implement effective visitor and resource management policy and gauge their success over time.

Monitoring programs can be of significant value by providing reliable information necessary to establish and evaluate resource protection policies, strategies, and actions. Monitoring programs provide an objective record of resource conditions, even though individual managers come and go. A monitoring program may help detect and evaluate trends when data are compared between present and past resource assessments. It may detect deteriorating conditions before severe or irreversible changes occur, allowing time to implement corrective actions. Analysis of monitoring data may assist in the selection of appropriate management actions and evaluate their efficacy over time.

A campsite monitoring program provides an essential component of recreation resource planning and management frameworks such as the VUM planning and decision-making framework. NPS Management Policies require approaches that identify and monitor changes in backcountry settings and establish thresholds (standards) of change based on desired resource and social conditions. Thresholds define the critical boundary line between acceptable and unacceptable conditions, establishing a measurable reference point against which future conditions can be compared. Monitoring provides the mechanism to periodically assess conditions for comparison with thresholds. Protocols included in Appendix 1 can be adapted to provide reliable methods for monitoring trail and recreation site conditions.

Finally, we note that while many managers recognize the benefits of a long-term monitoring program, that sustaining such a program with limited staff and funding can be challenging. An advantage of the A.T. community is the many trail-maintaining clubs and opportunities for collaboration with volunteers, including hikers, local residents, and universities. Notwithstanding the importance of quality assurance in the collection of monitoring data, it can be possible to involve volunteers in such data collection when adequate descriptive monitoring program protocols, training programs, technologies, and oversight are provided. For example, data can be collected in the field using phone apps that include protocol look-ups and quality assurance restrictions on data entry (e.g., a qualitative indicator might allow only the entry of a 1-4 value and will not allow someone to enter a 5 or leave the field blank). These phone apps can save increasingly accurate GPS positions and high-resolution digital photos with each monitoring record. The number of staff involved in monitoring can be limited to a small number of more experienced volunteers with periodic supervision or oversight to validate their work.

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APPENDIX 1: LIDAR DATA SPECIFICATIONS

LiDAR data specifications. NVA = Non-vegetated Vertical Accuracy; VVA = Vegetated Vertical Accuracy; FVA = Fundamental Vertical Accuracy; CVA = Consolidated Vertical Accuracy; SVA = Supplemental Vertical Accuracy; VPA = Vertical Positional Accuracy. Terminology for reporting vertical accuracy for data used in this study vary across datasets as guidelines were updated and new terminology created by ASPRS in 2015 (Abdullah et al., 2015). 2004 guidelines require vertical accuracy is reported as Fundamental Vertical Accuracy (FVA), representing accuracy in open terrain, Supplemental Vertical Accuracy (SVA), representing accuracy in different ground cover categories, and Consolidated Vertical Accuracy (CVA), representing a combined accuracy across ground covers (ASPRS Lidar Committee, 2004). The terms Non-vegetated Vertical Accuracy (NVA) and Vegetated Vertical Accuracy (VVA) replaced FVA and both SVA and CVA respectively with updated guidelines in 2015 (Abdullah et al., 2015).

State	Counties	First Deployed	Company	Sensor	Nominal Point Spacing	DEM Resolution	RMSEz	Source and Additional Information
CT	Litchfield	2016	Sanborn Map Company Inc.	Leica ALS70 w/MPiA LiDAR		0.6m	0.125 m NVA at 95% CI. 0.170m VVA	Connecticut Statewide LiDAR 2016, Capitol Region Council of Governments
MA	Berkshire	2015	Quantum Spatial	Leica ALS70	0.7	1m	0.138m NVA 0.287m VVA	The Maine and Massachusetts 2015 QL1 and QL2 LiDAR project
ME	Oxford, Franklin, Somerset, Piscataquis	2016	Quantum Spatial	Leica ALS70 (expected)	0.7	2m	0.113m NVA 0.253m VVA	Maine Office of GIS, 2016 QL2 Maine LiDAR Project.
NH	Grafton, Coos	2015	Quantum Spatial	Leica ALS70	0.7	.76m	0.093m NVA 0.284m VVA	New Hampshire Geographically Referenced Analysis and Information Transfer System (NH GRANIT)
NY	Putnam	2008	Sanborn Map Company Inc.	Optech ALTM 2050		2m	0.185m FVA 0.202m SVA (Forested)	FEMA Floodplain Map Modernization Program
NY	Duchess	2013	The Atlantic Group	Leica ALS70-HP	0.7	1m	0.13m FVA, 0.26m CVA 0.33m SVA (Forested)	USGS 3DEP Program
PA	Franklin, Cumberland, Perry, Dauphin	2007	unspecified (contracted by PAMAP Program, PA DCNR)	unspecified	1.4	1m	≤0.21m FVA ≤0.24m CVA	Pennsylvania Department of Conservation and Natural Resources
PA	Dauphin, Lebanon, Berks, Lehigh, Schuylkill, Carbon	2008	unspecified (contracted by PAMAP Program, PA DCNR)	unspecified	1.4	1m	≤0.24m FVA ≤0.26m CVA	Pennsylvania Department of Conservation and Natural Resources
TN	Sullivan, Johnson, Carter, Avery, Unicoi, Greene, Cocke, Sevier, Blount	2015	Woolpert, Inc.	Leica ALS70-HP lidar sensor	0.7	0.76m	0.096m NVA 0.169m VVA	Tennessee Department of Finance and Administration and partners
VA	Nelson, Augusta,	2015	Dewberry	Riegl 680i	0.7	0.76m	0.168m NVA 0.226m VVA	USGS Chesapeake Bay VA LiDAR Project
VA	Page, Madison, Rappahannock, Warren	2014	Photo Science, Inc.	Leica ALS70 Optech Gemini sensor	0.7	0.76m	0.092m FVA 0.150m SVA (Forested)	Shenandoah LiDAR Data Acquisition Project
VT	Windham, Bennington	2012	Northrop Grumman, Advanced GEOINT Solutions Operating Unit	Optech ALTM213	2	2m	0.15m FVA, 0.25m CVA 0.40m SVA (Forested)	Vermont Center for Geographic Information

APPENDIX 2: FIELD RESEARCH PROTOCOLS

Trail Assessment Manual

Appalachian National Scenic Trail

(*version 5/12/2017*)[1]

This manual describes procedures for conducting an assessment of resource conditions on the Appalachian Trail treadway. These procedures are designed so that they can be replicated, allowing future reassessments for monitoring trail conditions over time. A number of indicators are included to characterize factors expected to influence trail conditions or assess trail design attributes and sustainability. The A.T. tread will be evaluated at selected sample points located within five-kilometer sampled segments of the A.T. A spatially distributed GRTS sampling design was applied to determine the locations of the sampled segments and within each, 50 sample points where transects will be located.

Trail conditions will be characterized from measurements taken at the sample point transect locations. Measurements will document the trail's width, depth, substrate, slope, alignment and other characteristics. These procedures take several minutes to apply at each sample point. Data is summarized through statistical analyses to characterize resource conditions for each A.T. trail segment and for the entire trail system.

Assessments should be taken near the middle or end of the visitor use season but before leaf fall (e.g., June-August). Site conditions generally recover during the fall/winter/spring periods of lower visitation and reflect rapid impact during early (spring) season use. Site conditions are more stable during the summer months and reflect the resource impacts of that year's visitation. Subsequent assessments, if conducted, should be completed as close in timing to the original year's measures as possible. Generally monitoring should be replicated at about 5-10 year intervals, unless conditions are changing rapidly.

Materials (Check before leaving for the field)

- ✓ Day pack w/x-tra clothing, rain gear, lunch/snacks, water, water filter, hat, sunscreen, tick repellent, first aid kit, phones, wallets, car key, fanny pack, trash bags to cover packs in rain, other?
- ✓ A.T. topographic maps
- ✓ Both tablets w/charged battery plus power banks and connector cords, gallon trash bags for rain, umbrella
- ✓ Trimble GeoXT GPS w/charged and spare battery, stylus, and data dictionary. Loaded with A.T. corridor, treadway, and the Informal Trail data dictionary.
- ✓ Garmin 64 GPS unit w/charged & spare batteries loaded with the A.T. study segment endpoints and sample (transect) points
- ✓ This manual on waterproof paper
- ✓ Flexible transect line tape measure in centimeters (10 m retractable)
- ✓ Tape measure for CSA depths in centimeters (3.5m retractable)
- ✓ Small notebook and pens
- ✓ Stakes (2) and mini-hammer
- ✓ Metal binder clips (4+) to attach tape to stakes
- ✓ Compass/clinometer combo
- ✓ Pin flags and washers with flagging tape to mark transect locations, flag carrier
- ✓ Scrapers used to dig soil samples
- ✓ Digital camera for campsite photos or staff working photos

1 - Developed by Dr. Jeff Marion, DOI, U.S. Geological Survey, Patuxent Wildlife Research Center, Virginia Tech Field Station, Dept. of Forestry (0324), Blacksburg, VA 24061 (540/231-6603) Email: jmarion@vt.edu

Point Sampling Procedures

***Trail Segment Info*:** This will be collected later via e-mail and phone contacts to local A.T. trail club members responsible for the measured sections. Collect and record any information that is known about the trail segment's history, particularly its original construction date, relocation segments and dates, past uses, type and amount of maintenance, history of use, etc. These data need to be spatially documented, particularly the age of the trail and of relocations or major reconstruction work. This can be recorded on separate paper if a knowledgeable trail club member is present.

Use Level (UL): Also collected at a later date unless a trail club member is present. Record an estimate of the amount of use the trail receives from the most knowledgeable trail club member or agency staff. Work with them to quantify use levels on an annual basis (e.g., low use: about 100 users/wk for the 12 wk use season, about 30 users/wk for the 20 wk shoulder season, about 10 users/wk for the 20 wk off-season = about 2000 users/yr). Be sure that the use characteristics are relatively uniform over the entire 5k trail segment. Trails may have substantial changes in the amount of use over their length. For example, a road may intersect the A.T., significantly altering use levels. In these instances where substantial changes in the type and/or amount of use occur, the trail should be split in two or more segments with use characterized for each segment. This practice will facilitate the subsequent characterization of trail use. This can be recorded in the Segment form on the iPad or on separate paper.

Trail Name: Record a trail segment name based on an included geographic feature.

Surveyors: Record initials for the names of the trail survey crew.

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

Inventory Indicators

Consult the fieldwork planning information to determine the location of the next trail section to be measured, and the location of the best parking location to access the segment. Use a car GPS and tablet or phone maps to navigate there (if you need paper maps purchase and keep receipts). Recharge any devices not fully charged while driving. Park the car in the safest location possible, take all valuables that you can with you, hiding the rest under clothing in obscure locations, *lock all doors/close all windows*, leave nothing interesting or valuable "in view." Ensure that you have all field gear (fully charged with back-up batteries and cords), clothing, rain gear, food, and water before departing the car – *double-check this before you leave*.

Field staff will operate in two groups, the Trimble operator and the Transect crew. The Trimble operator is generally out front and will use the Garmin GPS in proximity alarm mode to navigate to each trail transect location. When the alarm goes off stop immediately and place wire pin flags on either side of the trail to mark the transect, *then record an averaged waypoint precisely at the center of the transect and trail with 50+ points, labelled with the Section and transect numbers* (e.g., 2115, Section 21, Transect 15). Do not under any circumstance subjectively "adjust" or move the transect point when the alarm goes off.

The Transect crew will also use a Garmin GPS in proximity mode to navigate to the transects. Sometimes the Garmin operator will be off mapping informal trails or measuring recreation sites and get behind the Transect crew. When this happens the Transect crew will locate and measure the transects, leaving behind two flags indicating the transects and one flag for the Upper Trail Watershed Boundary (UTWB) location for the Trimble operator to find, who will collect the flags *after* recording averaged waypoints.

Assess A.T. tread conditions at every sample point – no rejections are permitted even if a sample point occurs in a creek or on a road or sidewalk. We have made this decision so that the data accurately characterize the entire A.T. treadway. If an indicator cannot be assessed, e.g., is "Not Applicable," record a "-1". All data will be entered into a tablet computer (Apple iPad and Google Nexus 9). Field forms have been created for these using the Fulcrum software, open these and proceed with data entry.

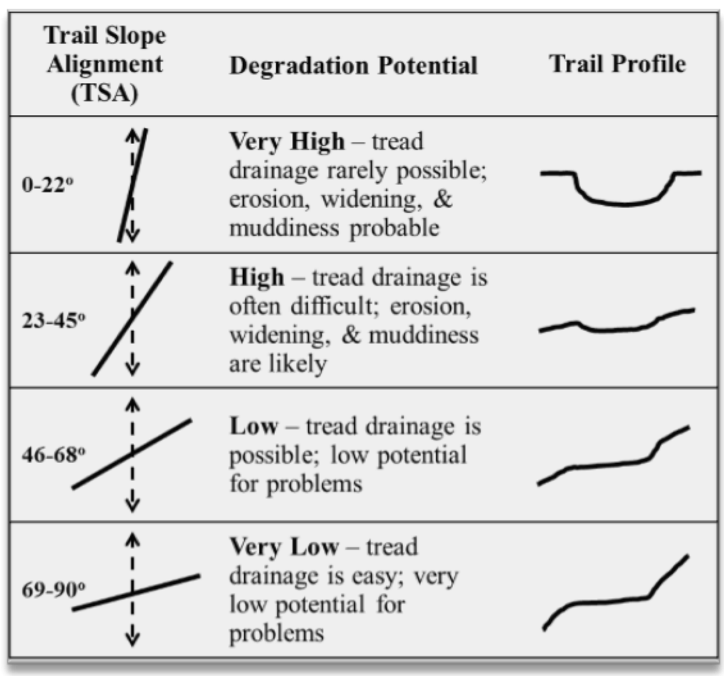
1) **Trail Segment/Transect:** Record a combined trail segment and transect number (4 digits). Ensure that a waypoint was recorded for each transect point.

2) **Soil Depth (SD):** Hammer the transect stakes into the ground in off-trail areas in the vicinity of the transect and use a tape measure to determine the typical soil depth to rock: 1=0, bedrock or scree field, 2=1-10 cm, 3=>10 cm. Omit if CSA is -1.

3) **Upslope Trail Grade (TG):** The two field staff should position themselves at the transect and about 3m (10 ft) in an uphill direction **on the trail** from the transect. Use the clinometer to determine the grade by sighting and aligning the horizontal line inside the clinometer with a spot on the opposite person at the same height as the first person's eyes. Note and record the nearest degree (left-side scale, record as a positive value). If at a local high point (everything within 3m is lower, record a neg. grade value).

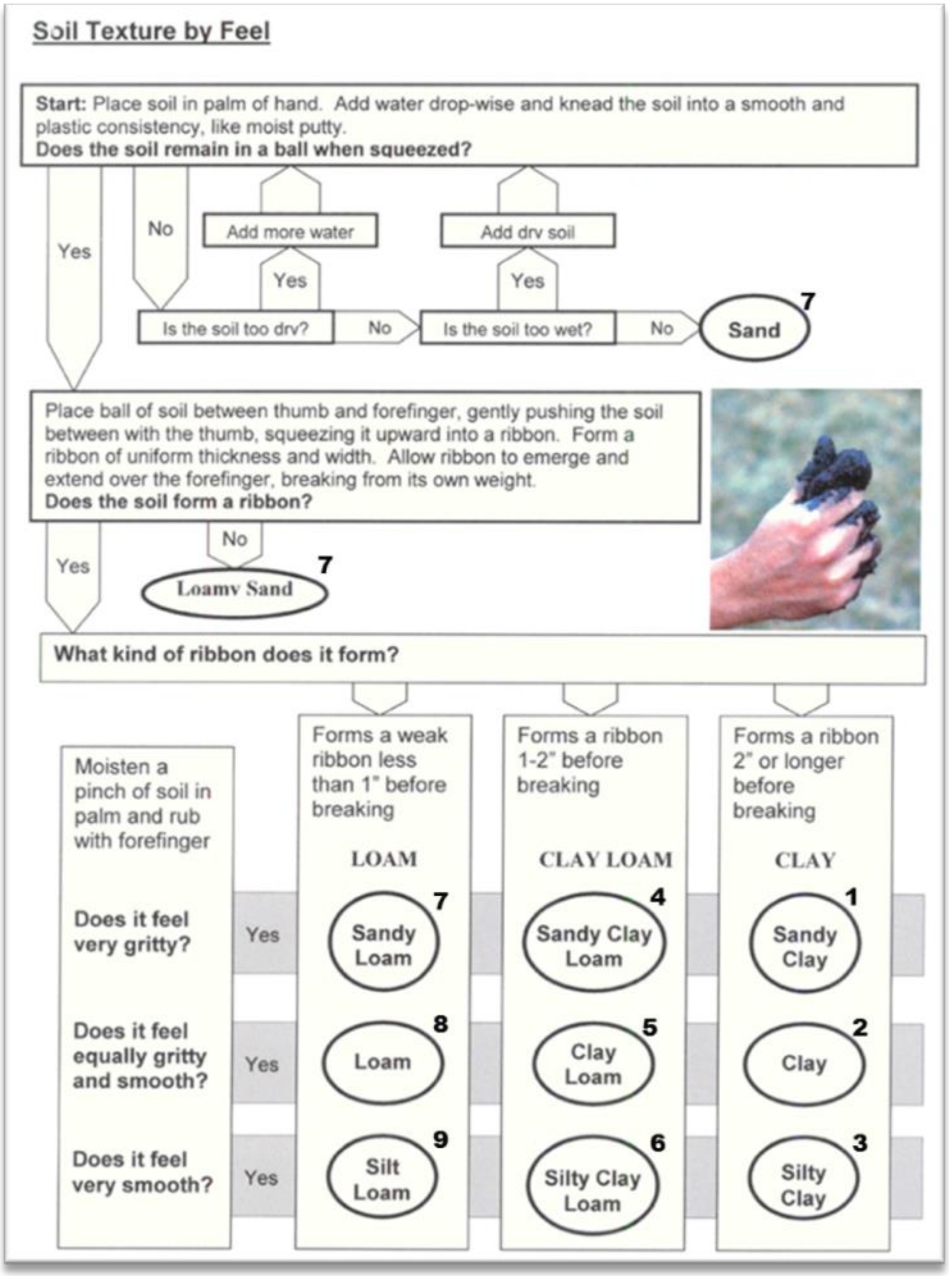
4) **Landform Grade (LG):** The two field staff should position themselves at the transect and about 3m (10 ft) in an uphill direction along the fall line beginning above any “cut” slope. Your objective is to measure the prevailing landform slope in the vicinity of the transect. Look in the clinometer side window and record the nearest degree (positive value) off the visible scale. If at a local high point (everything within 3m is lower, record a neg. grade value).

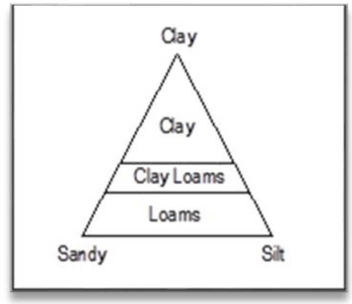
5-6) **Trail Slope Alignment Angle (TSA):** Looking directly uphill from the sample point, identify and project the fall-line across the A.T. Identify the fall line by thinking about where you would need to pour a bucket of water such that the water would run downhill and intercept the middle of the transect. Ignore the influence of adjacent large rocks and focus on averaged water movement over the uphill landscape. Chose the direction along the A.T. that makes an acute angle ($<90^{o}$) with the fall line. Sight the peep-hole compass along the A.T. in the acute angle direction (3m segment) and record as “Trail^{o}” the compass azimuth. Repeat to assess and record the azimuth of the fall line as “Fall Line^{o}”. The Trail Slope Alignment angle is calculated by subtracting the smaller from the larger azimuth (computed by the tablet) – ensure that it is $<90^{0}$. If at a local high point (everything within 3m is lower, record a -1).

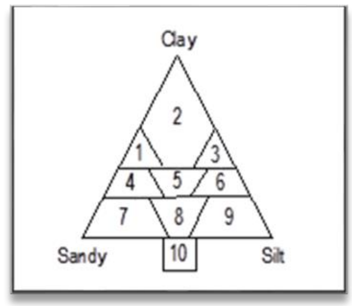


Trail Slope Alignment (TSA)	Degradation Potential	Trail Profile
0-22°	**Very High** – tread drainage rarely possible; erosion, widening, & muddiness probable	
23-45°	**High** – tread drainage is often difficult; erosion, widening, & muddiness are likely	
46-68°	**Low** – tread drainage is possible; low potential for problems	
69-90°	**Very Low** – tread drainage is easy; very low potential for problems	

7) **Soil Texture (TX):** Use the scraper to remove any thin (<1 cm) of organic soil near the center of the tread. Then excavate soil about the size of a golf ball (4 cm, 1.5 in). Follow the field method described below to describe soil texture at the sample point. This assessment should be done at the start of the trail segment (have some water to use and rinse your hands with). At the following transects you can often check the texture without wetting, but repeat the full method if it appears to have changed.







Record a classification:

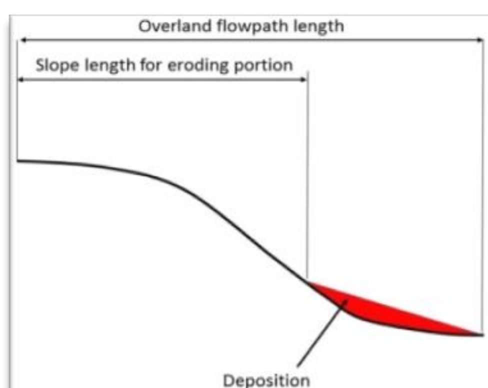
1 - Sandy Clay
2 - Clay
3 - Silty Clay
4 - Sandy Clay Loam
5 - Clay Loam
6 - Silty Clay Loam
7 - Sandy Loam
8 - Loam
9 - Silt Loam
10 - Black Organic Soil
11 - Rock, gravel, pavement, boardwalk

8) **Erosion/Deposition (ED):** Characterize general soil movement at the transect (see illustration):

a) Erosion Zone – a sloping area that could yield soil (soil loss may not be visually evident),

b) Deposition Zone – at the foot of a slope or in a flat or depressed area where soil deposition may be occurring (generally has dark organic soil at the surface),

c) Neither – a flat area with no evidence of deposition, transects with substantial rock or gravel, and bog bridging, roads, sidewalks, and streams.



9) **Tread Type (TT):** Record the *predominant* type of tread substrate material within a 20 cm (8 in) band centered on the transect, (under vegetation, leaves, or water) using these categories: 1=Soil/organic muck, 2=Bedrock, 3=Rock (from cobble to boulder), 4=Bog bridge (planks), 5=Boardwalk (decking/bridge), 6=Dirt or gravel Rd, 7=Paved Rd, 8=Rock step/rock-work, 9=Sidewalk, 10=Streams.

10) **Rugosity (R):** For a 3m (9.8 ft) segment of trail centered on the transect and looking uphill to identify the level of tread rugosity: 1=Smooth, few roots or rocks that would cause a hiker to slow or move laterally, 2=Intermediate, 3=Rough, lots of roots or rocks that would substantially slow hikers and cause them to move laterally and pick a way through.

11) **Offsite Vegetation (OV):** Record the predominant vegetation cover within a 2m (6.5 ft) band on either side of the trail: 1=Organic litter and/or moss/lichen (shady) (rhododendron), 2=10-50% herbaceous vegetation cover, 3=51-100 herbaceous vegetation cover, 4=mostly grass and/or sedge cover (sunny), 5=mostly rock, little vegetation.

12) **Secondary Treads (ST):** Count the number of trails differentiated from the main tread by strips (>50cm) of mostly undisturbed vegetation or organic litter, regardless of their length, that closely parallel the main tread at the transect. *Do not count the main tread.*

13) **Organic Litter (OL):** Record the presence/absence and predominant type of organic litter off-trail in the vicinity of the transect: 1=Leaves, 2=Needles, 3=None to rare.

Impact Indicators

Transect Establishment: A great deal of judgment based on a variety of factors will determine the placement of the transect trail tread boundary stakes and measurement tape. Accurate and precise Cross Sectional Area (CSA) soil loss measures depend on your configuration of these items.

Trail Tread Boundaries: Examine the Figure 1 photos illustrating different types of tread boundary determinations. Tread boundaries are defined as the most pronounced outer boundary of visually obvious human disturbance created by trail use (not trail maintenance like vegetation clearing). These boundaries are defined as pronounced trampling-related changes in ground vegetation height (trampled vs. untrampled), cover, composition (broadleaf herbs vs. grasses), or when vegetation cover is reduced or absent, changes in organic litter (intact vs. pulverized) (see photo illustrations in Figure 1). The objective is to define the trail tread that receives the majority (>95%) of traffic, selecting the most visually obvious outer boundary that can be most consistently identified by you and future trail surveyors. Where helpful it is appropriate to examine the adjacent 3 meters on either side of the transect location to project trail boundaries from there to define the tread boundaries at the transect point.

- Include any secondary parallel treads within the transect only when they are not differentiated from the main tread by strips (>50cm) of mostly undisturbed vegetation or organic litter.
- If the trail is on stonework (rock steps, armored treads, stepping stones) use the width of stonework unless there is visible evidence of walking on bordering rocks or around them. Omit CSA measures (record a -1).
- If the trail is on a sidewalk, bog bridging, or boardwalk measure the width of the feature and omit the CSA measures (record -1). If there is a discernable trail on adjacent soil/veg/rocks then conduct transect and CSA measures there.
- Omit transect and CSA measures (record -1) if point is located on a road or creek.
- If the trail is on rock you may be able to reasonably deduce the tread boundaries based on vegetation (plants, moss, lichen) or rock trampling disturbance at the transect or as projected from adjacent areas. Conduct CSA measures only if you determine that the rock was originally covered by soil (otherwise record a 0). If one or both boundaries are still a complete guess, then record a -1 for tread width and CSA.

Figure 1. Photographs illustrating different types of boundary determinations. Trail tread boundaries are defined as the most pronounced outer boundary of visually obvious human disturbance created by trail use (not trail maintenance like vegetation clearing). These boundaries are defined as pronounced changes in ground vegetation height (trampled vs. untrampled), cover, composition, or, when vegetation cover is reduced or absent, as pronounced changes in organic litter (intact vs. pulverized).

CSA soil loss measures also require different procedures based on the type of trail and erosion. Refer to Figure 2 and these definitions:

***Direct-ascent vs. side-hill trails**:* Trails, regardless of their grade, that more or less directly ascend the slope of the landform are direct-ascent or "fall-line" trails. Direct-ascent trails involve little or no tread construction work at their creation – generally consisting of removal of vegetation and organic litter and then "walked-in." Trails that angle up a slope *and* require a noticeable amount of cut-and-fill digging in mineral soil (generally on landform slopes of greater than about 10%) are termed side-hill trails. Soil excavation and fill work is required to create a gently out-sloped bench to serve as a tread. Separate procedures are needed for side-hill trails to avoid including construction-related soil movement in our measures of soil loss following construction.

Recent vs. historic erosion: Recreation-related soil loss that is relatively recent is of greater importance to protected land managers and monitoring objectives. Severe erosion from historic, possibly pre-recreational use activities, is both less important and more difficult to reliably measure. Historic erosion is defined as adjacent erosion that occurred in the past and is not currently within the tread. When trails follow old road-beds, bull-dozer work may also have removed soil that will be indistinguishable from historic erosion. Including this form of soil loss as "historic erosion" is unavoidable.

a) **Direct-ascent trails, recent erosion**: Refer to Figure 2a. Place stakes and the transect measurement tape to characterize what you judge to be the *pre-trail original land surface*. Place the left-hand stake so that the bottom of the transect tape sits on what you believe was the "original" ground surface but at the edge of any tread incision, if present (see Figure 2a). This option generally always applies to shallow or deeply rutted trails with near-vertical sides.

b) **Direct-ascent trails w/historic erosion**: Refer to Figure 2b. If you judge that some of the erosion is historic then follow these procedures. There should be an eroded tread within a larger erosional feature. Place the stakes at the current trail tread boundaries and stretch the transect tape to allow measurements of the more recent recreation-related erosion (if present). For this configuration the tape should generally be slid all the way down the stakes to the ground so that the CSA measurements begin and end with 0 values. Perform the CSA measurements described below, then reconfigure the transect line to measure historic erosion by placing the stakes and tape to conform with the original land surface as depicted in Figure 2b. Then follow the Historic Erosion measurement guidance in the next section.

c) **Side-hill trail**: Refer to Figure 2c. The objective of this option is to place the transect stakes and tape to simulate the post-construction pre-use tread surface. When constructing side-hill trails upslope soil is excavated and shifted downslope as fill to create a gently out-sloped bench (most agency guidance specify a 3-5% out-slope) for the tread surface (see Figure 2c). Out-sloped treads drain water across their surface, preventing the buildup of larger quantities of water that become erosive. However, constructed treads generally become incised over time due to soil erosion, displacement, and compaction. ***Note that a raised berm is often found along the lower edge of older side-hill trails. This may be from soil loss occurring from the tread but recognize that soil and organic litter displaced from the trail or the side-slope above the trail is often deposited here, raising the height of the berm above the "original" tread surface.***

   Carefully study the tread in the vicinity of the sample point to judge what you believe to be the post-construction tread surface. Pay close attention to the tree roots, rocks, lichen/moss cover on rocks, and bath-tub rings or lines on the rock to help you judge the post-construction tread surface. Look in adjacent undisturbed areas to see the extent to which roots and rocks are exposed naturally or the approximate depth of their burial. Configure the stakes and transect line to approximate what you judge to be the post-construction pre-use tread surface. If a berm is present along the lower side of the trail use your judgment based on exposed tread roots and rocks to determine if the berm surface reflects the height of the post-construction tread surface or, as shown in Figure 2c, if it was raised by displaced tread or upslope soil.

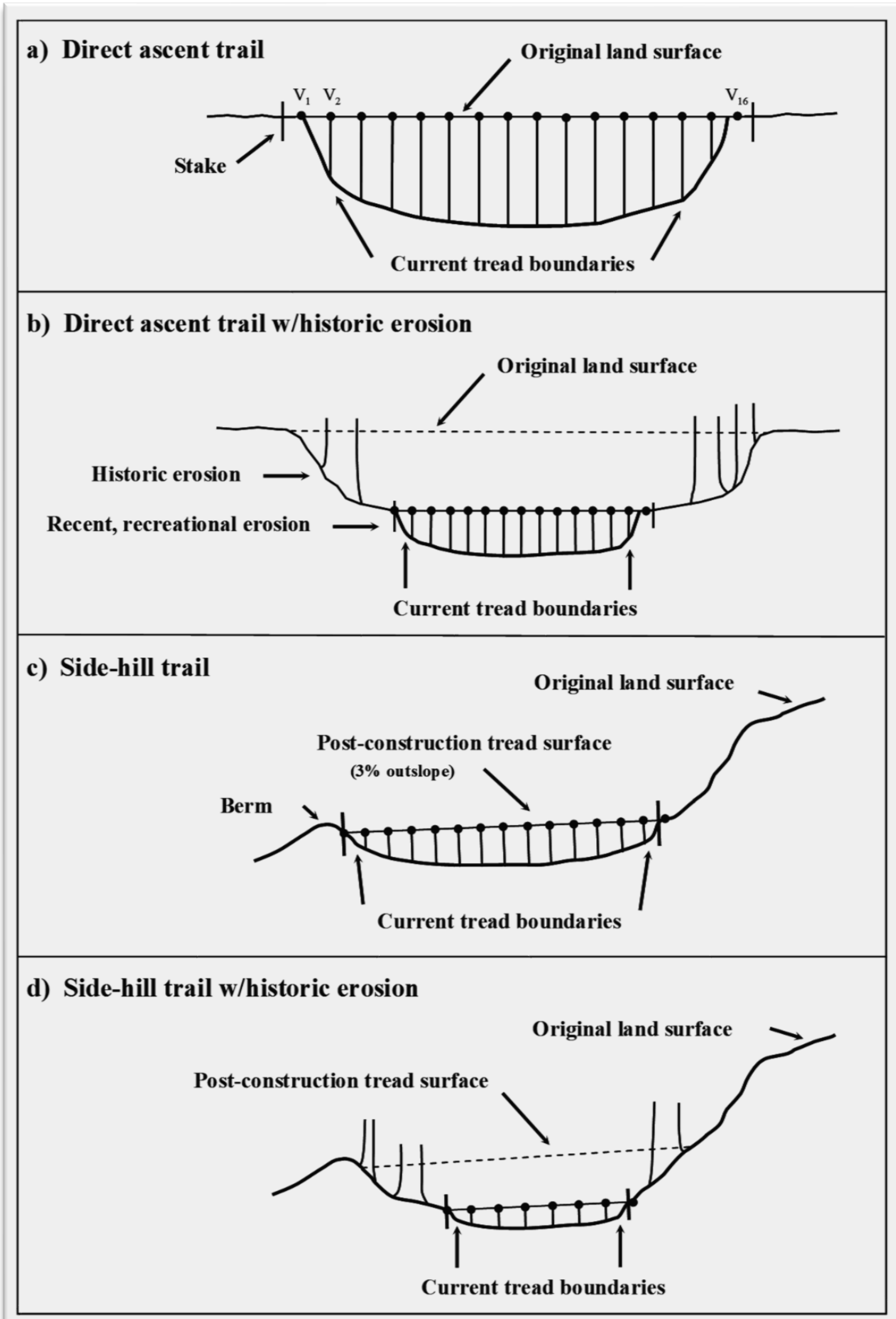


Figure 2. Cross sectional area (CSA) diagrams illustrating alternative measurement procedures for direct ascent trail alignments (a & b) vs. side-hill trail alignments (c & d) and for relatively recent erosion (a & c) vs. historic erosion (b & d).

Determine the transect tape height on the metal stake on the side you are most certain of and affix it with a binder clip. If you are fairly certain of the tape height on the opposite side then pull the tape tight and affix it

to the other metal stake. The slope of the transect line should generally be to the downhill side and be less than 5% or 3°. If uncertain, assume that the original trail outslope was about 5% or 3° and affix the line on the opposite side based on a 5% or 3° outslope using the clinometer (this does not apply to fall-aligned trails). Note that in some circumstances configuring the transect tape will result in it being elevated above the base of either boundary stake so that the first or last vertical CSA measure is >0; this is acceptable.

d) **Side-hill trail with historic erosion**: Refer to Figure 2d. If you judge that some of the erosion is historic then follow these procedures. There should be an eroded tread within a larger erosional feature. Place the stakes at the current trail tread boundaries and stretch the transect tape to allow measurements of the more recent recreation-related erosion (if present). Perform the CSA measurements described below, then reconfigure the transect line to measure historic erosion by placing the stakes and tape to conform with the original post-construction tread surface as depicted in Figure 2d. Then follow the Historic Erosion measurement guidance in the next section. Note that in some circumstances configuring the transect tape will result in it being elevated above the base of either boundary stake; this is acceptable.

Measurement Procedure: Hammer the steel border stakes in at each tread boundary making sure that the transect line will be perpendicular to the tread at that location. If stakes can't be inserted into the ground then have your partner hold it in place during the measurements, or move large rocks to sandwich the stake between them. The stakes have black marking located at 5 cm intervals, when possible insert the stakes so that the post-construction tread surface aligns with one of these markings. Place binder clips on the stakes so that the bottom of the binder clip aligns with what you judge to be the post-construction pre-use tread surface.

Stretch the transect measurement tape between the stakes configured using your best judgment to reflect the post-construction pre-use tread surface at the bottom of the tape. Refer to the above guidance under letters a-d for configuring the height of the transect measurement tape, noting the differences between fall-line and side-hill trails and those with historic erosion. If rocks or roots obstruct the transect tape then offset the tape upwards in 5 cm increments as needed following the guidance below. The tape on the left side should be affixed with a binder clip ***so the stake is at the "0" point of the tape***, secure the opposite end by pulling the tape tightly, then wrapping it around the stake and securing with another binder clip. The tape needs to be tight - any bowing in the middle will bias measurements.

Take vertical soil loss measures ***perpendicular to the measurement tape*** every 10 cm along the transect tape beginning at the left-hand stake, measuring from the bottom of the transect measurement tape to the trail tread surface (measure through water to soil/rock and to the base of all organic materials; do not move rocks). Take and record these vertical CSA values to the nearest 0.5 cm (e.g., 3.0, 3.5, 4.0, 4.5 and so on). Note: if the trail is extremely wide such that CSA measures every 10 cm are too time-consuming (e.g., trail is >2m (6.5 ft) wide), then you can change the measurement interval to 20 cm; ***be sure to record this change on the tablet data form!***

Measurement Tape Obstructions*:* For all transects, if the transect tape cannot be configured properly due to obstructing rocks or roots, then you must offset the line upward in 5 cm increments the same amount on both steel transect boundary stakes. Refer to the photo below, noting that both stakes should be adjusted up or down when possible so that one of the 5 cm markings is aligned with what you believe to be the post-construction tread surface. Leave a pair of binder clips on the stakes to show the location of the post-construction tread surface aligned with the bottom of the binder clips. Attach the offset tape with an additional pair of binder clips. If you use an offset ***be sure to call out and record*** on the tablet the exact amount of the offset in centimeters so that the offset distance can be subtracted from the CSA measures during data analyses.

14) **Tread Width (TW):** See prior "Trail Tread Boundary" guidance. Measure and record the length of the transect (tread width between the tread boundary stakes) to the nearest 0.5 centimeter (e.g., 45.0, 45.5, 46.0 cm). Omit for all roads and when tread boundaries are indistinguishable.

15) **Cross-Sectional Area (CSA):** See prior "Trail Tread Boundary" guidance. The objective of the CSA measure is to measure trail soil loss from the estimated post-construction pre-use tread surface to the current tread between the trail boundary stakes. Note that CSA soil loss measures reflect all of the following: erosion by water or wind, soil displacement from trail users, and soil compaction. Record all the vertical CSA measures based on the guidance above beginning at the left-hand stake. See earlier guidance on when to record a -1 for CSA. The tablet form software will calculate and provide the correct number of data entry spaces based on dividing the tread width by the tread interval.

16) **CSA Transect Measurement Interval (TMI)**: This is normally 10 cm but can be changed to 20 cm for trails wider than 2 m or 200 cm. Record the interval value used for this transect.

17) **Transect Line Offset (TLO):** Record the transect line offset as 0 or the number of centimeters necessary to raise the transect tape above obstructing rocks or roots. Ensure that the line was offset equal amounts on both boundary stakes.

18) **Maximum Incision (MI):** Select and measure along the transect line the maximum incision value, recorded to the nearest 0.5 centimeter (e.g., 4.0, 4.5, 5.0 cm). Assess only when CSA is not -1.

Transect Photos: Take two transect photos with the stakes and transect tape configured as you measured it:

Oblique photo – move the tablet back or forward along the trail until you capture the entire transect plus about 2 ft of adjacent terrain on either side of the transect stakes. Position the tablet so that the background looking down the trail beyond the transect is also captured. **Vertical photo** – hold the tablet directly above the transect tape and take a photo that includes both stakes (when possible) and shows the tread conditions. *Check both photos for focus and exposure and retake them when needed.*

Metadata and transect link: The photos are linked by the tablet form software to the transect field forms but we need a back-up if they somehow become un-linked. It is critical that the photos retain the "Date/time created" and the GPS metadata so that they can be linked to the date/time field for the transect form and the Trimble GPS averaged point saved for each transect.

19-28) **Tread Condition Characteristics:** Along a 20 cm (8 in) band centered on the transect, estimate to the nearest 10% (5% where necessary) the aggregate proportion occupied by any of the mutually exclusive *tread surface* categories listed below. **Be sure that your estimates sum to 100%**.

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

Historic Erosion: Replicate the Transect Establishment Procedures from above to configure the tape measure to reflect any historic erosion if present. This alignment should disregard the current tread boundaries and instead reflect your judgement of any historic soil loss.

29) **Historic Tread Width (HTW):** Measure and record the length of the transect (tread width) to the nearest centimeter (e.g., 45.0, 45.5, 46.0 cm). Omit if CSA is a -1.

30) **Historic Maximum Incision (HMI):** Select and measure along the transect line the maximum incision value, recorded to the nearest 0.5 centimeter (e.g., 4.0, 4.5, 5.0 cm). Omit if CSA is a -1.

31) **Upper Trail Watershed Boundary (UTWB):** Walk in an uphill direction from the trail transect up to 50 m (164 ft) (determined by counting your paces) until you reach a point where you estimate that nearly all water running down the trail during a rainstorm would flow off the trail. This may due to a human-constructed water bar or drainage dip, a natural feature (e.g., tree root, rock, or dip), strong tread out-sloping, or where the tread would no longer carry water due to loose rock. Record an averaged waypoint with the Trimble at this location (N=10+ points) labelled with the transect number for the most recent transect followed by the letter "B". Omit if CSA is a -1.

32) **Trail Watershed Grade (TWG):** Walking from the transect to the UTWB, position the transect staff 5 m (16 ft) apart and assess percent trail grade with the clinometer, recording up to 6 measures. Omit if CSA is a -1.

33) **Tread Watershed Substrate:** Examine the tread watershed substrate from the transect to the UTWB and record the percentage of the tread that is soil (including soil covered by leaves, organic debris, and vegetation but excluding organic muck, boardwalks, roots, or rock). Omit if CSA is a -1.

34) **Drainage Feature Type (DFT):** Record the type of drainage feature at the UTWB: 1) Wood water bar, 2) Rock water bar, 3) Drainage dip, 4) Grade reversal (natural or man-made), 5) Tread out-sloping, 6) Natural rocks, 7) Exposed roots, 8) Other. Omit if CSA is a -1.

Special Study on Mud-holes (Conducted in 2016, with indicators 35-37added in 2017)

We need a substantially larger sample of transects located at mud-holes to enable multiple regression modeling of the factors that contribute to the development of mud-holes and how we can design trails to prevent their occurrence. While hiking to, or when surveying each A.T. section, stop at every occurrence of mud-holes that are at least one meter long, including locations that are currently dry. The objective is to measure only mud-holes that are lasting, not ones that dry up two days after a rain. Establish a transect at the center of the mud-hole and assess it using the standard transect protocols. Label the transect with the letters "mud" followed by the nearest section and transect number and record an averaged point with the Trimble. In addition to the standard transect photos take additional photos clearly showing the lowermost "drainage" area and the principal area that is supplying water to the mud-hole.

35) **Source of water:** Determine the source of the water feeding the mud-hole:
1) Spring or seep, 2) intermittent or perennial stream, 3) rain-water, 4) high water table (swampy area).

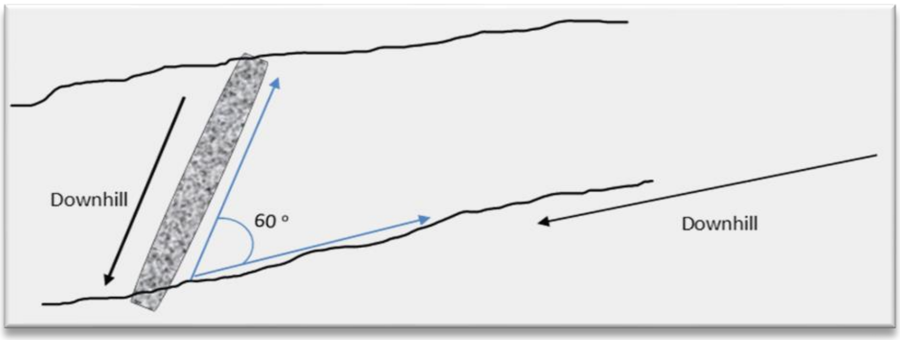
36) **Mud-hole Cause:** Determine why the mud-hole formed:
1) Flat-terrain, tread has a rut or depression that retains water,
2) Side-hill (sloping) terrain, tread has a berm and other obstructions that prevent water drainage.

37) **Ease of Correction:** Record the most appropriate response using your judgement:
1) Mud-hole could be easily drained by cleaning an existing drainage ditch,
2) Mud-hole could be drained by digging a new drainage ditch (<5 ft long x <1ft depth),
3) Mud-hole could be drained by digging a new drainage ditch (5-10 ft long and/or 1-2 ft depth),
4) Drainage is too difficult, should consider trail relocation, boardwalks, stone steps, or other action.

Special Study on Tread Drainage Features (TDFs) (Conducted in 2016)

We will be conducting a special study to examine the alignment angle and efficacy of tread drainage features (TDFs), including wood or rock water bars, and drainage ditch/berm features constructed of soil. This will not include any natural TDF or grade reversals. We hope to achieve assessments of at least 250 TDF's to enable statistical analyses so we need about 12 TDF assessments per segment. We expect some segments to lack TDF's so let's assess the first 20 TDF's encountered in each A.T. segment and you can stop assessments when we have 250 (or 300 if it's not too big a burden). It may be easiest to complete all other measurements first and assess the TDF's on the return trip.

When you encounter a qualifying TDF stop and assess it only if the grade is ≥3% and there is no obvious evidence of cleaning in the current year (i.e., someone dug out the sediment deposited on the uphill side of the TDF. Look for evidence of the excavation or excavated soil within 10 ft. Open the TDF tablet field form and complete the following indicators.



38) **<u>TDF Uphill Trail Grade (TWTG):</u>** Two field staff should position themselves at the TDF and about 10m (30 ft) in an uphill direction **on the trail** from the TDF. Use the clinometer to determine the grade by sighting and aligning the horizontal line inside the clinometer with a spot on the opposite person at the same height as the first person's eyes. Note and record the nearest degree (left-side scale, record as a positive value).

39) **<u>Tread Drainage Feature Angle (TDFA):</u>** Use a protractor to measure the acute angle of the TDF.

40) **<u>Tread Drainage Feature Depth:</u>** Looking at downhill half of the TDF (the direction of water flow) estimate the shallowest depth from the top of the TDF to the soil. Measure this to the nearest 0.5 cm.

41) **<u>Tread Drainage Feature Deposition Depth</u>**: From the apex of trail border and TDF, move upslope until you find a spot that is 10 cm in from the TDF and Trail boundary, measure here. Scrape down to the original soil substrate and measure to the nearest 0.5 cm the depth of the soil that has been deposited down to the original soil substrate. Be careful not to measure the mound of soil you might have created with the scraping; only measure to the top edge of what was there. Record a -1 if you are unable to reliably measure a depth.

42) **<u>Tread Drainage Feature Efficacy (TDFE):</u>** Looking at the TDF estimate how much water you think it would divert off the trail in a heavy rainstorm.

0-25%	TDF would divert 0-25% of water off the trail
26-50%	TDF would divert 26-50% of water off the trail
51-75%	TDF would divert 51-75% of water off the trail
76-100%	TDF would divert 76-100% of the water off the trail

43) **<u>TDF Photo:</u>** Take a photo of the TDF from the uphill side at an oblique angle with tablet 1 ft above the center of the trail showing the entire TDF and about 1-2 ft on either side (if water is going around the TDF include that in the photo).

44) **<u>TDF Waypoint:</u>** Use the Trimble to record an averaged waypoint (N=10+ points) labelled with the trail segment number followed by the letters "TDF" and consecutive numbers beginning with 1.

Informal Trail Assessment Manual

Appalachian National Scenic Trail

(*version 5/15/2017*)[1]

This manual describes procedures for conducting inventories and resource condition assessments of informal (visitor-created) trails along the Appalachian National Scenic Trail (A.T.). The creation and proliferation of informal trails can directly impact sensitive plant communities, rare or endangered flora and fauna, and wildlife habitats. For example, a small patch or population of rare plants may be eliminated by trampling, habitat changes caused by visitor use, or through competition from non-native species introduced by park visitors (Eagleston & Marion 2018). Recreationists seeking to access scenic overlooks, water resources, or merely to explore, often trample vegetation sufficiently to create extensive informal trail networks. Such unplanned trail networks generally receive no environmental reviews and resource degradation is often severe due to their lack of professional design, construction, and maintenance. While some degree of visitor impact is unavoidable, excessive trail impacts threaten natural resource values, visitor safety, and the quality of recreational experiences.

These protocols are designed to document the number, lineal extent, spatial distribution, area of trampling disturbance, and resource condition of all informal trails within the A.T. study corridor (150 m wide, 492 ft, including adjacent official A.T. shelter and camping areas), which will be identified on GPS devices employed during fieldwork. Careful searches of the A.T. corridor will be conducted to locate and assess all informal trails within sampled 5k study segments. Assessment procedures are efficiently applied through walking surveys that employ Trimble sub-meter accuracy Global Positioning System (GPS) units, providing field staff a paperless method for collecting trail inventory and resource condition data. When periodically collected over time, these data assist with the monitoring of onsite resource conditions and provide long-term documentation of the existence, location, and condition of informal trails. The data also provide supporting information for management decisions, such as to evaluate which informal trails should be closed or left open, and later to evaluate the success of management efforts to close selected trails, prevent the creation of new trails, or prevent further deterioration of existing trails.

Assessments should be taken near the middle or end of the visitor use season but before leaf fall (e.g., June-September). Site conditions generally recover during the fall/winter/spring periods of lower visitation and reflect rapid impact during early (spring) season use. Site conditions are more stable during the mid- to late-use season and reflect the resource impacts of that year's visitation. Subsequent assessments, if conducted, should be completed as close in timing to the original year's measures as possible. Generally monitoring should be replicated at about 5-10 year intervals, unless conditions are changing rapidly.

Materials (Check before leaving for the field)

- ✓ Topographic and detailed road maps
- ✓ Trimble GeoXT GPS (use most accurate unit available), spare battery, stylus, antenna/lead, and data dictionary. Loaded with A.T. corridor, treadway, and the Informal Trail data dictionary.
- ✓ This manual on waterproof paper
- ✓ Backup field forms (forms/photos from previous survey)
- ✓ Tape measure (6ft auto-retracting)
- ✓ Small notebook and pens

1 - Developed by Dr. Jeremy Wimpey and Dr. Jeff Marion, DOI, U.S. Geological Survey, Patuxent Wildlife Research Center, Virginia Tech Field Station, Department of Forestry (0324), Blacksburg, VA 24061 (540/231-6603) email: jmarion@vt.edu.

Methods

Survey staff should be familiar with study area and its visitor use patterns, particularly where visitors are most likely to depart formal trails and potential off-trail destinations. Scheduling field surveys during times of optimal satellite constellations may be necessary for some areas, or returning to an area at a later time when signal reception is more optimal.

Begin work by selecting an area (sub-region of the A.T. study segment) on the paper map to search. Use features such as trails, roads, and streams, along with prior survey data and personal knowledge, to divide the area into manageable units. Prior data should be used as a guide but not as an authoritative catalog of where informal trails will be found and mapped. To ensure that all informal trails are located, walk all formal trails and search the areas adjacent to each trail for informal trails. Also check the boundaries of campsites and recreation sites.

Do not assess trails created and/or used predominantly by wildlife (e.g., deer) – those that go under low-hanging branches that would obstruct human traffic. Be spatially aware and thoroughly search along/near formal trails and features for areas that are likely to draw visitors off the formal trail network (e.g., vistas, water bodies, geographic features of interest, historic structures). In particular, beware of informal trails that depart a formal trail on resistance surfaces (e.g., rock, gravel, bare soil, grass) that may hide the beginning of an informal trail. Some random searching and walking transects across off-trail areas, particularly near any features of interest, may be necessary to locate and map all informal trails. Include discontinuous trails and those that are blocked by brush, scree-walls, or fencing. Do not record any mapped or formal (official) blazed or signed trails.

When an informal trail is located, begin an informal trail segment using the IT data dictionary. Use the Condition Class descriptors below to determine and record the appropriate condition class. Do not begin walking the trail segment until the GPS has successfully recorded its first position fix. Walk the trail while collecting the feature until it reaches a junction or changes condition class. Assess and record the segment's average trail width (see below) and then close the segment in the GPS.

Trail width is defined as the most visually obvious outer boundary of trampling-related disturbance that receives the majority (>95%) of traffic. These boundaries are defined by pronounced changes in ground vegetation height (trampled vs. untrampled), cover, composition, or, when vegetation cover is reduced or absent, by disturbance to organic litter (intact vs. pulverized) or lichen. Include any secondary parallel treads within this assessment only when they are not differentiated from the main tread by strips of less disturbed vegetation or organic matter. See Figure 1 for photographs illustrating these trail boundary definitions.

Always stop at trail junctions (beginning and end of every IT segment) to record an averaged IT trail junction point (n=10 points). These points improve the accuracy of GIS data editing.

Decision rules for Collecting Informal Trail segments

A condition class change that occurs for less than 2 meters (approximately 6 feet) can be ignored (i.e. collect it as one segment and assign the dominant condition class to the segment). Be careful to try to avoid collecting animal trails. These trails will be narrow and have low hanging branches/vegetation. Use your judgment and look for signs of human and animal use (footprints, litter, deer browse, etc.).

Condition Class Structure

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

Surveying Tips

- Use the pause and resume (log) capabilities of the GPS to prevent collecting extraneous points at the beginning and end of a segment. Pause the logger when not moving; restart it as you resume movement.
- Working in pairs or using flagging tape and or pin flags will help when the IT network is very dense. Flag sub regions on the ground and work through them individually.
    - When working a dense network work small sub areas and utilize flags and landmarks to delineate them; when collection has been completed within one flagged sub area, establish an adjacent sub area and collect it (e.g., 50-100 m long on one side of a formal trail).
- Collect IT anchor points when needed to aid in tying trail junctions to a specific location. Use Trimble's nest feature option.
- Use the formal trail layer and paper maps as a reference.

Data Download and Backup

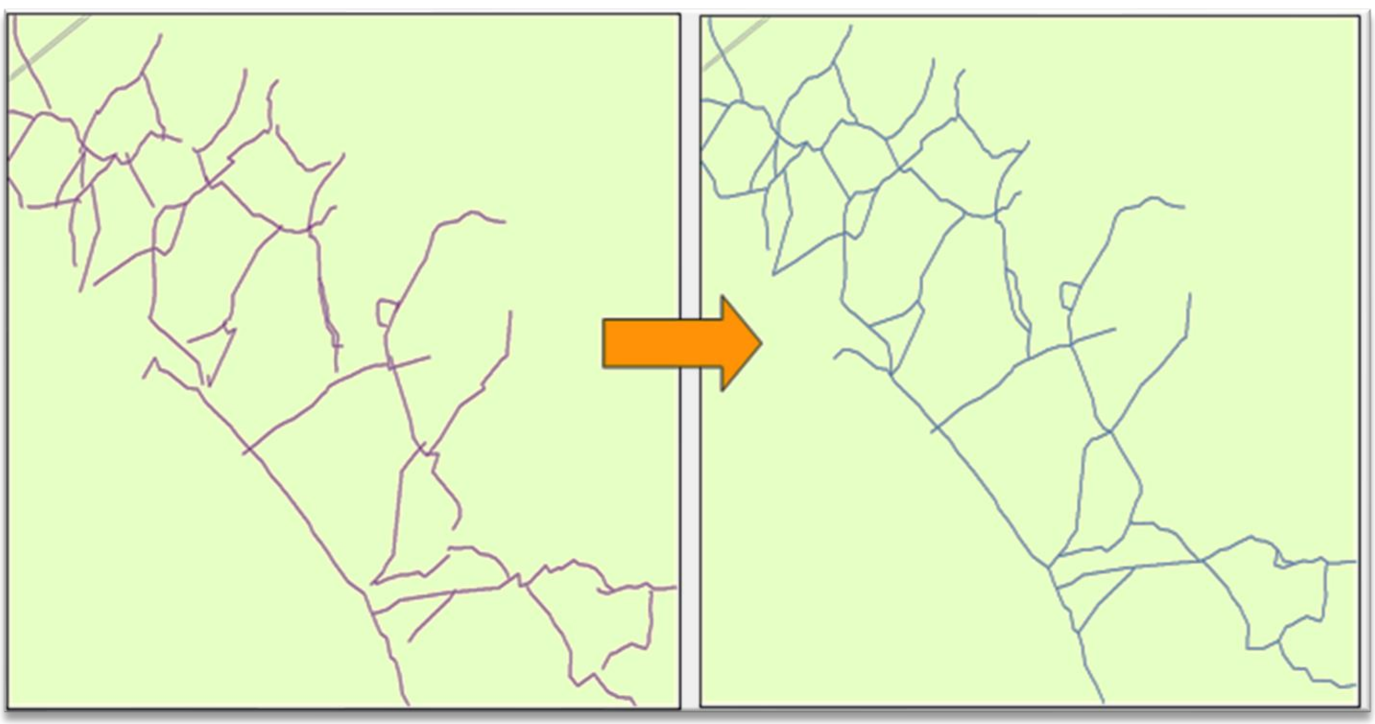
- When finished collecting for the day, close the rover file on the Trimble GPS.
- Connect the GPS to a computer with Pathfinder Office software (work within the preexisting project directory for the current collection).
- Transfer the rover files to the computer.
- If an internet connection is available, download the differential correction files that correspond to all new rover files and differentially correct them.
    - Designate the source base station as the closest available geographically.
    - Review the correction report as well as the corrected files for any errors or processing problems. Open the files in GIS to visually inspect them each day.
    - Ensure that the data were not removed during the correction procedure (e.g., due to missing base station data, high PDOP, etc).
    - Correction files that are not immediately available are generally made available within a week or two.
- Backup all data on a separate HDD and document all necessary metadata.
- Recharge the GPS and external battery.
- Keep a written field notebook record of all fieldwork, including field staff names, search areas, dates/times, and computer filenames.

Editing Data

Data should be post-processed (differentially corrected and converted to GIS appropriate format) using GPS software (e.g., Trimble's Pathfinder Office with conversion to ArcMAP Shapefiles). Merge output files into a single file representing the Informal trail network.

Informal trail data requires editing due to the nature of GPS data collection. GIS staff should edit the data to clean up and improve the accuracy of the informal trail network. Tips for doing this work:

- Use imagery and ancillary GIS datasets to help visualize the local environment.
- Move trail segment endpoints (minimally) to establish connectivity to other informal segments, recreation sites, and formal trails.
    - Use the anchor points layer for establishing junction locations.
- Use snapping and zoom tools to assist.
- Once the network is close, a "clean" or "build" procedure can be used (adjust fuzzy tolerance and dangle length as needed).



Before Editing — After Editing

Data Dictionary

Informal Trail:

LineFeature

Label1=Average Width
Condition Class: Menu; Normal, Normal
1 2 3 4 5 Other

Average Width=Numeric, Decimal Places=0
Minimum=1,Maximum=144,DefaultValue=8 Normal, Normal

Segment#:
Numeric, Decimal Places=0
Minimum=0, Maximum=500, Default Value=1, StepValue=1 Normal, Normal

Comment:
Text, Maximum Length=30 Normal, Normal

IT Anchor Point:

Feature

Label1=Number
Label2=Comment

Number=Numeric Decimal Places=0
Minimum=0,Maximum=500, DefaultValue=1, StepValue=1 Normal, Normal

Comment:
Text, Maximum Length=30 Normal, Normal

Recreation Site Assessment Manual

Appalachian National Scenic Trail

(*version 5/15/2017*)[1,2]

This manual describes procedures for conducting inventories and resource condition assessments of recreation sites (including campsites, shelters, and all day-use sites) along the Appalachian National Scenic Trail (A.T.). Procedures are also described for future reassessments to allow monitoring of site conditions over time. These procedures will document and permit monitoring of changes in site conditions and allow statistical modeling to evaluate factors that influence site conditions. Three general approaches are used for assessing site conditions: 1) photographs from permanently referenced photo points, 2) a condition class assessment determined by visual comparison with described levels of trampling impact, and 3) predominantly measurement-based assessments of several impact indicators.

For the purposes of this manual, recreation sites are defined as areas of visually obvious disturbed vegetation, surface litter, or substrates caused by human use located within the A.T. study corridor (150 m wide, 492 ft, including within adjacent official A.T. shelter and camping areas), which will be identified on GPS devices employed during fieldwork. Careful searches of the A.T. corridor will be conducted to locate and assess all campsites and recreation sites within the sampled 5k study segments. There must be sufficient trampling-related disturbance to produce visually obvious site boundaries, otherwise no measurements will occur. Recreation sites receive mostly day-time activities whereas campsites receive mostly overnight use, though both uses can occur on the same sites.

Assessments should be taken near the middle or end of the visitor use season but before leaf fall (e.g., June-September). Site conditions generally recover during the fall/winter/spring periods of lower visitation and reflect rapid impact during early (spring) season use. Site conditions are more stable during the mid- to late-use season and reflect the resource impacts of that year's visitation. Subsequent assessments, if conducted, should be completed as close in timing to the original year's measures as possible. Generally monitoring should be replicated at about 5-10 year intervals, unless conditions are changing rapidly.

Materials (Check before leaving for the field)

- ✓ Topographic and detailed road maps
- ✓ Trimble GPS unit w/spare battery, stylus, antenna/lead, and the Site data dictionary. Loaded with A.T. corridor, treadway, and data dictionary for data entry.
- ✓ Sonin Combo Pro distance measuring unit w/fresh batteries, tape measure (100 ft. in tenths) as backup
- ✓ This manual on waterproof paper with field forms (forms/photos from previous survey)
- ✓ Tablet computer with forms for data entry, backup power supply, gallon trash bag & umbrella for rain.
- ✓ Clipboard, monitoring manual, blank field forms (some on waterproof paper), small notebook, calculator, pens

1 – Developed by Dr. Jeff Marion, DOI U.S. Geological Survey, Patuxent Wildlife Research Center, Virginia Tech Field Station, Dept. of Forestry (0324), Blacksburg, VA 24061 (540/231-6603) email: jmarion@vt.edu.

2 – Photographs illustrating site boundaries, vegetative ground cover classes, soil exposure, tree damage, and root exposure are part of this manual. High quality reproductions of these photographs may be found in:

Marion, Jeffrey L. 1991. Developing a natural resource inventory and monitoring program for visitor impacts on recreation sites: A procedural manual. DOI, National Park Service, Natural Resources Report NPS/NRVT/NRR-91/06, pages 46-51.

General Site Information

1) **Site Number**: Record the Section Number followed by a unique site number.
2) **Inventoried by**: Identify the name of field personnel assessing the site.
3) **GPS**: GPS coordinates for site, WGS84 datum. Use the Trimble GPS and collect at averaged point at the center of each recreation site. Record the code for this waypoint here.
4) **Date**: Month, day, and year the site was evaluated (e.g. July 1, 2017 = 07/01/17).
5) **Location**: Record an area name (e.g., Mount Rogers, Rhododendron Gap).

Comments: Comments concerning the site and its location: note any assessments that were particularly difficult or subjective, problems with monitoring procedures or their application, suggestions for clarifying monitoring procedures, descriptions of particularly significant impacts beyond site boundaries (quantify if possible), or any other comments you feel may be useful.

Inventory Indicators

6) **Site Expansion Potential**: P = Poor expansion potential - off-site areas are completely unsuitable for any expansion due to steep slopes, rockiness, dense vegetation, and/or poor drainage, M = Moderate expansion potential - off-site areas moderately unsuitable for expansion due to the factors listed above, and G = Good expansion potential - off-site areas are suitable for site expansion, features listed above provide no effective resistance to site expansion.
7) **Site Expansion Potential**: A sustainable campsite should stay its designed size in perpetuity, bounded by adjacent offsite areas that are not conducive to tenting or other camping activities due to sloping topography (generally >15%) or substantial rockiness. Sustainable practice should not rely on woody vegetation as this can change over time due to forest succession, wildfires, or tree cutting. Estimate the percentage of area within a 50 ft "doughnut" buffer zone beyond the current campsite boundary that would inhibit all tenting activity; e.g., a value of 80% means that 80% of the surrounding area cannot easily be used for camping due to steeply sloping terrain or rockiness.
8) **Tree Canopy Cover**: Imagine that the sun is directly overhead and estimate the percentage of the site that is shaded by the tree canopy cover; record the mid-point value. Note: use "85.5" for nearly full to full tree canopy cover over the site; use "98" only if the cover is fairly dense or thick.

	0-5%	6-25%	26-50%	51-75%	76-95%	96-100%
Midpoints:	**2.5**	**15.5**	**38**	**63**	**85.5**	**98**

9) **Rock Substrate**: Estimate the percentage of rock substrate within recreation site boundaries (see below). The rock may be bedrock, boulders, or cobble - barren or covered with lichens/moss.

	0-5%	6-25%	26-50%	51-75%	76-95%	96-100%
Midpoints:	**2.5**	**15.5**	**38**	**63**	**85.5**	**98**

10) **Use Type**: Record the predominant use based on your observations: Campsite, regular = C, Side-hill Campsite = SC, Shelter = S, Vista = V, Trail junction or rest/waiting spot = R, Unknown (combination) = U. Use comment field to note when camping appears to be occurring on sites that are predominantly vista, trail junction, or spring sites.
11) **Use Type Comment**: More descriptive information on the type of site if needed.
12) **Use Level**: Low = L, Moderate = M, Heavy = H Obtain from local club members or agency staff when possible.

Impact Indicators

Identify the approximate center of the recreation site and collect an average point (n=30). The most efficient method for measuring the recreation site's size is to walk the boundary slowly with the Trimble GPS in collecting mode (also do this for satellite sites). Set GPS PDOP at 6 initially and if point collection is excessively slow change it to 8 (but be sure to change back to 6 afterwards). Be sure to wait on point collection beeps before turns and to examine the resulting image for accuracy. If inaccurate, use the log later function to collect averaged points (n=5-10) at campsite vertices. If this is also inaccurate, then apply the Geometric Figure method to measure and record the recreation site size.

The first step is to establish the site's boundaries and measure its size. These describe the **Geometric Figure Method** for determining site size – it is quite accurate when applied with good judgment. Carefully study the site's shape, as if you were looking down from above. Mentally superimpose and arrange one or more simple geometric figures to closely match the site boundaries. Any combination and orientation of these figures is permissible (see Figure 1). Project site boundaries straight across areas where trails enter the site.

Include any adjacent associated ***"satellite"*** tenting spots or use sites. Satellite spots are often small adjacent tenting sites (1-2 tent pads) but can also be a privy or spring/stream site where visitors obtain water. Use your judgment to separate out and exclude nearby campsites or day-use sites – measure these separately. In areas of high-density camping you should first measure the largest "core" site, aggregating all sites that share common boundaries. Then measure the adjacent campsites, attaching smaller satellite tenting areas to them if present.

Sometimes (rarely) there can be an essentially ***"undisturbed island"*** of vegetation within a camp or recreation site boundary. If present, measure and record the dimensions of these islands in the comment field – their area will be subtracted from the campsite or recreation site area.

Identify site boundaries by pronounced human trampling-related changes in vegetation cover, vegetation height/disturbance, vegetation composition, surface organic litter, and topography (illustrative photographs will be provided to field staff during training). Many sites with dense forest overstories will have very little vegetation and it will be necessary to identify boundaries by examining changes in organic litter, i.e. leaves which are untrampled and intact vs. leaves which are pulverized or absent. Include only those areas that appear to have been disturbed from human trampling. Natural factors such as dense shade can create areas lacking vegetative cover – do not include these areas if they appear "natural" to you. When in doubt, it may also be helpful to speculate on which areas typical visitors might use based on factors such as slope or rockiness. If you cannot discern visitor trampling-related disturbance boundaries this area then ignore it and move on.

Good judgment is required in making the necessary measurements of each geometric figure. As boundaries will never perfectly match the shapes of geometric figures, you will have to mentally balance disturbed and undisturbed areas included and excluded from the geometric figures used. For example, in measuring an oval site with a rectangular figure, you would have to exclude some of the disturbed area along each side in order to balance out some of the undisturbed area included at each of the four corners. It may help, at least initially, to place plastic tape or wire flags at the corners of each geometric figure used. In addition, be sure that the opposite sides of rectangles or squares are the same length. Measure (nearest 1/10th foot) the dimensions necessary for computing the area of each geometric figure using the Sonin units (see operating instruction at end of this manual).

Sketch the shape(s) of all necessary geometric figures on a small notebook page, including satellites or undisturbed islands, then measure and record the necessary dimensions. Use a solar pocket calculator to obtain the total area and, if present subtract the area of undisturbed islands, recording the final disturbance area under indicator 13. Take your time and be very careful in making your calculations.

13) **Total Site Area**: Calculate and enter the total disturbed area (size) of the campsite or recreation site in square feet.

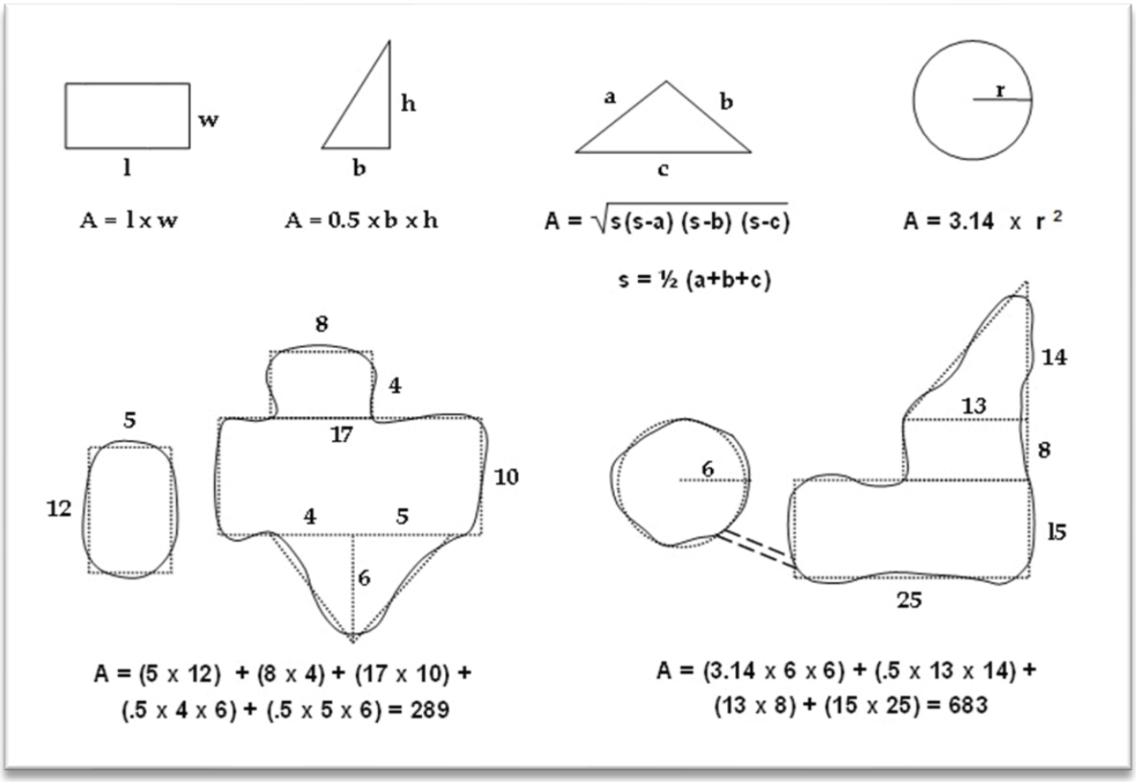


Figure 1. The Geometric Figure Method for determining the size of recreation sites.

14) **Condition Class**: Record a site Condition Class using the descriptions below.

Rock (R): Site is predominantly on rock surfaces so the effects of trampling are difficult to see/assess.

Class 1: Site barely distinguishable; slight loss of vegetation cover and /or minimal disturbance of organic litter.
Class 2: Site obvious; vegetation cover lost and/or organic litter pulverized in primary use areas.
Class 3: Vegetation cover lost and/or organic litter pulverized on much of the site, some bare soil exposed in primary use areas.
Class 4: Nearly complete or total loss of vegetation cover and organic litter, bare soil widespread.
Class 5: Soil erosion obvious, as indicated by exposed tree roots and rocks and/or gullying.

15) **Vegetation Ground Cover On-Site**: An estimate of the percentage of live vegetative ground cover < 2 ft tall (including herbs, grasses, tree seedlings, shrubs, mosses, and folios (leaf-like) lichens) within the site boundaries using the coded categories listed below (refer to photographs). Exclude crustose lichens, those that closely adhere to rock, as these are difficult to discern and are considerably less susceptible to trampling impacts. Include any disturbed "satellite" use areas and exclude undisturbed "islands" of vegetation. For this and the following two indicators, it is often helpful to narrow your decision to two categories and concentrate on the boundary that separates them. For example, if the vegetation cover is either category (6-25%) or category (26-50%), you can simplify your decision by focusing on whether vegetative cover is greater than 25%. Record only the midpoint value.

	0-5%	6-25%	26-50%	51-75%	76-95%	96-100%
Midpoints:	**2.5**	**15.5**	**38**	**63**	**85.5**	**98**

16) **Vegetation Ground Cover Off-Site**: An estimate of the percentage of live vegetative ground cover < 2 ft tall (same as above) in an adjacent "control" area that lacks human disturbance. Use the categories listed above.

The control site should be similar to the site in slope, tree canopy cover (extent of sunlight penetration), and other relevant environmental conditions. The intent is to locate an area which would closely resemble the site area had the site never been used. In instances where you cannot decide between two categories, select the category with less vegetative cover. The rationale for this is simply that the first visitors would tend to select a site with the least amount of vegetation. Note that if some of the substrates on the recreation site would likely be barren due to flooding or exposed bedrock then the control vegetation estimates must reflect that.

17) **Exposed Soil**: An estimate of the percentage of exposed soil, defined as ground with very little or no organic litter (partially decomposed leaf, needle, or twig litter) or vegetation cover, within the site boundaries and satellite use areas (refer to the photographs). Dark organic soil, the decomposed product of organic litter, should be assessed as bare soil when its consistency resembles peat moss. Assessments of exposed soil may be difficult when organic litter forms a patchwork with areas of bare soil. If patches of organic material are relatively thin and few in number, the entire area should be assessed as bare soil. Otherwise, the patches of organic litter should be mentally combined and excluded from assessments. Code as for vegetative cover.

18-20) **Tree Damage**: Tally each live tree (>1 in. diameter at 4.5 ft.) within or on site boundaries to one of the tree damage rating classes described below (refer to the photographs following these procedures). **Include** trees within undisturbed "islands" and **exclude** trees in disturbed "satellite" areas. Assessments are restricted to all trees within the flagged site boundaries in order to ensure consistency with future measurements. Multiple tree stems from the same species that are joined at or above ground level should be counted as one tree when assessing damage to any of its stems. Assess a cut stem on a multiple-stemmed tree as tree damage, not as a stump. Do not count tree stumps as tree damage. Take into account tree size. For example, damage for a small tree would be considerably less in size than damage for a large tree. Where obvious, assess trees with scars from natural causes (e.g., lightning strikes) as None/Slight.

None/Slight: No or slight damage such as broken or cut smaller branches, one nail, or a few superficial trunk scars or worn bark.

Moderate: Numerous small trunk scars and/or nails or one moderate-sized scar. Abraded bark exposing the inner wood.

Severe: Trunk scars numerous with many that are large and have penetrated to the inner wood; any complete girdling of tree (cutting through tree bark all the way around tree).

21-23) **Root Exposure**: Tally each live tree (>1 in. diameter at 4.5 ft.) within or on site boundaries to one of the root exposure rating classes described below. **Include** trees within undisturbed "islands" and **exclude** trees in disturbed "satellite" areas. Assessments are restricted to all trees within the flagged site boundaries in order to ensure consistency with future measurements. Where obvious, assess trees with roots exposed by natural causes (e.g., stream/river flooding) as None/Slight.

None/Slight: No or slight root exposure such as is typical in adjacent offsite areas.

Moderate: Top half of many major roots exposed more than one foot from base of tree. Generally indicative of soil loss of 2-4 inches.

Severe: Three-quarters or more of major roots exposed more than one foot from base of tree; soil erosion obvious. Generally indicative of soil loss of >4 inches

24) **Number of Tree Stumps**: A count of the number of tree stumps (> 1 in. diameter at ground and less than 4.5 feet tall) within or on-site boundaries. **Include** trees within undisturbed "islands" and **exclude** trees in disturbed "satellite" areas. Do not include windthrown trees with their trunks still attached or cut stems from a multiple-stemmed tree.

25) **Campfire Sites:** A count of the number of sites where a campfire has been built within site boundaries. Disregard locations where coals or ashes appear to have been dumped or scattered.

26) **Access Trails:** A count of all trails leading away from the outer site boundaries. For trails that branch apart or merge together just beyond site boundaries, count the number of separate trails at a distance of 10 ft. from site boundaries. Do not count extremely faint trails that have untrampled tall herbs in their tread.

27) **Site Photograph:** Select a vantage point that provides the best view of the entire site. Take photos with the camera pointed down to include as much of the site groundcover as possible. The intent of this photo is to positively identify the site ***and*** record a visual image of its condition. Retake the photo if the lighting is bad or it's out of focus. ***Enter the photo number.***

Special Study on Hammock Impacts (Conducted in 2016)

28) **Hammock Impact:** Search the campsite and adjacent off-site areas up to 20 meters for pairs of hammock support trees that are approximately 10-17 feet apart. Walk around each tree and examine the trunk and limbs for possible bark damage within the 4-7 ft range. Refer to the set of photos illustrating each condition class rating below, recognizing that damage from axes, hatchets, saws, and knives must be "omitted" from this assessment.

Code separately by tree location: 1) Within or on shelter/campsite boundaries, or 2) Outside but within 20 meters of shelter/campsite boundaries. If you identify any campsite trees rated Class 2-4 then also count and record the total number of trees within and on campsite boundaries. Take representative photos of tree damage at class 2 and 3 and take a photo of all trees rated class 4.

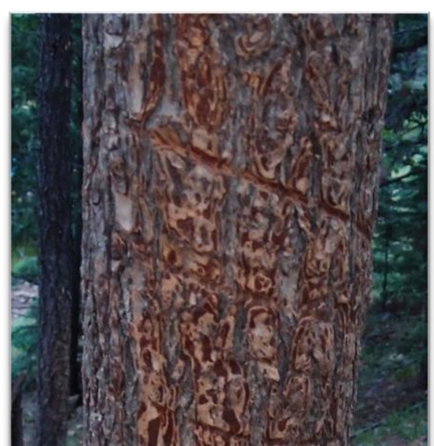
Class 1: No visible damage to tree bark that can be attributed to hammock use.

Class 2: Minor damage consisting of a few flaked patches of bark or minor bark compression.

Class 3: Intermediate damage consisting of missing and broken pieces of bark and visually obvious compression of bark.

Class 4: Substantial damage consisting of substantial loss or damage to bark and/or wear and severe compression of bark.

Condition Class 2 (above), 3, and 4 (right)



- **Collect all gear and clothing before leaving.**

Instructions on Use of Sonin Combo Pro: Read the Sonin manual. We will only use it in the target or dual unit mode. Turn main receiver unit on by pressing switch up to the double icons, turn target unit on and slide the protector shield up. The units power down automatically after 4 minutes of inactivity. Position units at opposite ends of segment to be measured, pointing the receiver sensors in a perpendicular orientation towards the target sensors. **Note:** The measurement is calculated from the base of the receiver and the back of the target, position units accordingly so that you measure precisely the distance you intended. Press and hold down the button with the line over the triangle symbol. The receiver will continue to take and display measurements as long as you depress the button. Wait until you achieve a consistent measurement, then release the button to freeze the measurement. Measures initially appear in feet/inches. To obtain conversions, press and hold the "C" button until the measure is converted to the units you want (tenths of a foot). Turn both devices off and store in protective case following use. Unit range is supposed to be 250 ft.; be careful and take multiple measures for distances over 100 ft. Under optimal conditions accuracy is within 4 in. at 60 ft. Device can be affected by temperature, altitude and barometric pressure, and noise (even strong wind). The units are not waterproof. **Batteries**: Carry spare batteries (2 9-volt alkaline). (Cost: $90)

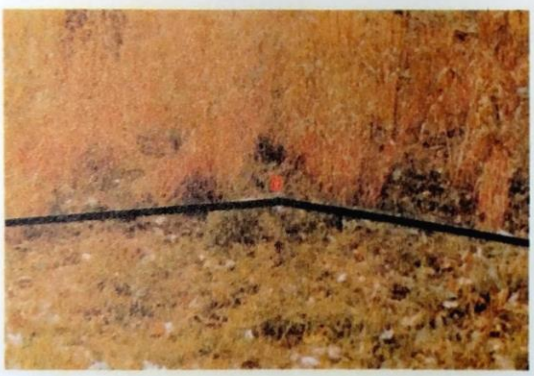
Supporting Photos

SITE BOUNDARIES

Identified by pronounced changes in vegetation, organic litter, or topography.

Vegetation Cover

Vegetation Composition



Vegetation Height/Disturbance

Topography

Organic Litter

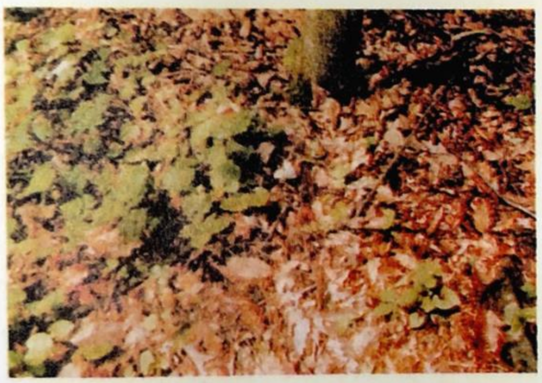
Organic Litter

VEGETATIVE GROUND COVER

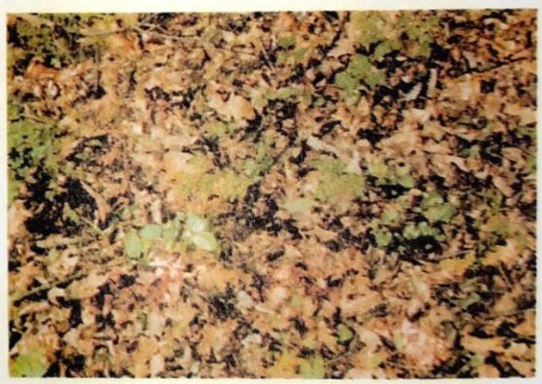
Live non-woody vegetative ground cover (including herbs, grasses, and mosses).

1=0-5%

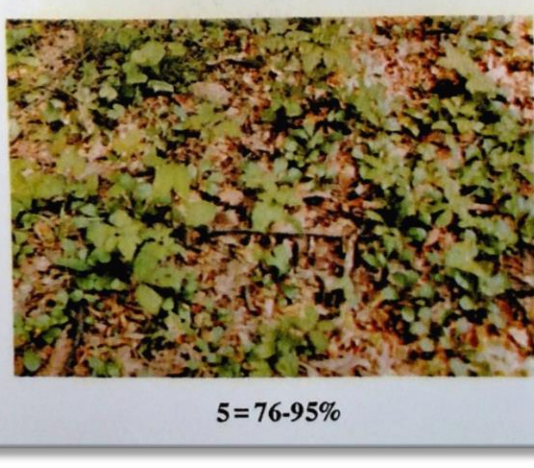
2=6-25%



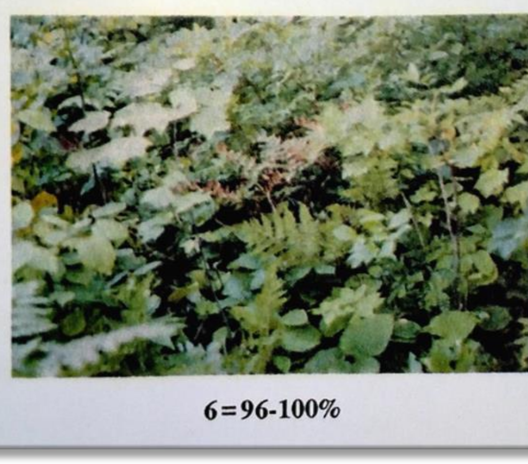
3=26-50%



4=51-75%



5=76-95%



6=96-100%

SOIL EXPOSURE

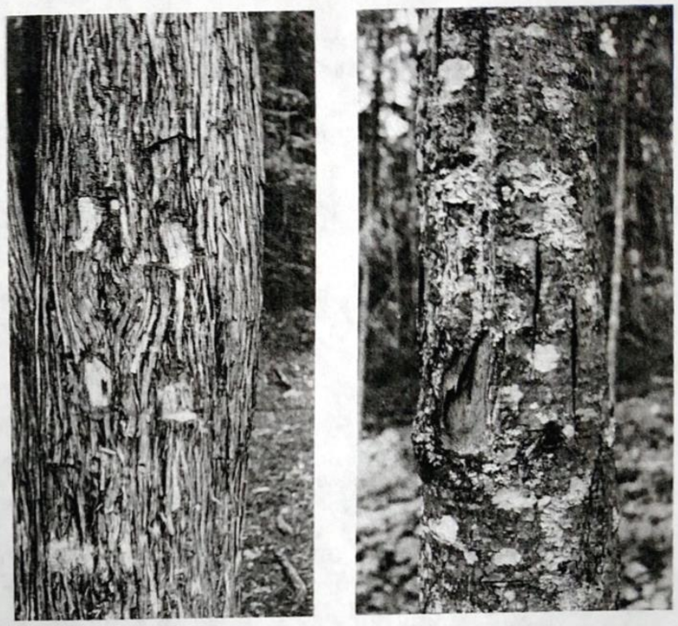
Areas of predominantly bare soil; very little or no organic litter or vegetation cove

Organic litter on left is pulverized but still covers underlying organic and mineral soil. Dark organic soil on right, which covers lighter colored mineral soil, should be assessed as bare soil.

As organic litter is pulverized and eroded from sites the remaining materials often clump together, resulting in a patchwork of organic litter and bare soil which is difficult to evaluate. If patches of organic material are relatively thin and few in number, as illustrated in the photo above, the entire area should be assessed as bare soil. Otherwise, the patches of organic litter should be mentally combined and excluded from assessments.

TREE DAMAGE

NONE/SLIGHT

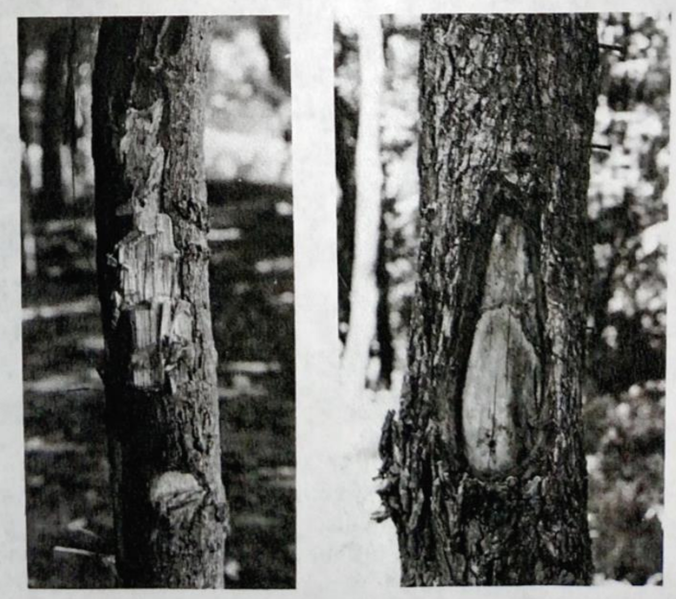


MODERATE

NONE/SLIGHT: No or slight damage such as broken or cut smaller branches, 1 nail, or a few superficial trunk scars.

MODERATE: Numerous small trunk scars and nails or 1 moderate sized scar.

SEVERE: Trunk scars numerous with many that are large and have penetrated to the inner wood; any complete girdling of tree.



SEVERE

ROOT EXPOSURE

NONE/SLIGHT: No or slight root exposure such as is typical in adjacent offsite areas.

MODERATE: Top half of many major roots exposed more than 1 foot from base of tree.

SEVERE: Three-quarters or more of major roots exposed more than 1 foot from base of tree; soil erosion obvious.

NONE/SLIGHT

MODERATE

SEVERE