Modeling Areal Measures of Campsite Impacts on the Appalachian National Scenic Trail, USA Using Airborne LiDAR and Field Collected Data

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GENERAL AUDIENCE ABSTRACT

Many land management agencies, both in the U.S. and internationally, have dual, competing objectives related to the sustainability of recreation: one to protect the quality of natural resources and one to provide for recreational access and experiences. Increasing visitation has the potential to negatively impact natural resources and threaten the quality of visitors' experiences on public lands. The majority of recreation impacts occur as a result of visitors spending time on or near recreation sites (e.g. campsites or vistas) or visitors traveling between these recreation sites on trail corridors. A widely accepted and practiced key strategy for managing trail systems is containing use to a sustainably designed and managed formal trail system. Campsites are also key infrastructure for recreational uses, however many protected areas have an inventory of campsites that are mostly visitor selected and created, and are excessively large due to site expansion and present in excessive numbers due to site proliferation.

While the practice of closing undesirable campsites is common in many managed areas, emphasis on actively shifting use to campsites selected or designed for sustainability has been largely ignored. Study objectives were to identify which use-related, environmental, and managerial factors significantly contribute to limiting areal impacts on campsites and to understand the relative influence of each. Field collected data of a 10% sample of campsites along the Appalachian Trail were used in conjunction with data generated using high-resolution elevation data to look at which characteristics relate to areal impacts using multiple regression. Chosen variables in regressions explained 64% of the variation in campsite size and 61% of the variation in the area of vegetation loss on a campsite. Results indicate four variables managers can utilize to enhance the sustainability of campsites: use level, overnight site type, and terrain characteristics relating to slope and topographic roughness. Results support indirect management methods that rely on the design and location of campsites and trails and not the effectiveness of enforcement or restricting visitor freedom. Techniques and concepts presented aid in identifying and creating ecologically sustainable campsites.

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ACADEMIC ABSTRACT

A successful campsite containment strategy reduces aggregate campsite impacts by shifting use to a smaller inventory of campsites that remain small over time. This research evaluates the relative influence of environmental and topographic factors, both collected in the field and modeled in GIS using high-resolution topography (LiDAR) data, on areal measures of campsite impact utilizing Least Absolute Shrinkage and Selection Operator (LASSO) penalized regression for factor selection and Ordinary Least Squares (OLS) for regressions. Chosen variables in regressions explained 64% of the variation in campsite size and 61% of the variation in the area of vegetation loss on a campsite. Results indicate four variables managers can utilize to enhance the sustainability of campsites: use level, overnight site type, and terrain characteristics relating to slope and topographic roughness. Results support indirect management methods that rely on the design and location of campsites and trails and not the effectiveness of enforcement or restricting visitor freedom. Techniques and concepts presented aid in identifying and creating ecologically sustainable campsites.

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CHAPTER 1: INTRODUCTION

Recreation on public lands has increased dramatically over the last few decades. A review of use trends in the 21st century by Hammitt et al. (2015) indicate that outdoor recreation has steadily increased since the 1990's. In 2015 the National Park Service (NPS) accommodated about 307 million recreational visitors, up from about 256 million in 1990 - an increase of 51 million visitors in just 10 years (National Park Service, 2015). Globally, protected areas cumulatively receive about 8 billion visits per year, more than 80% of those visits occurring in Europe and North America (Balmford et al., 2015).

Increasing visitation has the potential to negatively impact natural resources and threaten the quality of visitors' experiences on public lands. Whittaker et al. (2011) define impact as, "…any undesirable visitor-related biophysical change to natural resources". Recreation-related impacts are associated with vegetation, soils, water and wildlife and have been widely studied. Many land management agencies, both in the U.S. and internationally, have dual, competing objectives related to recreational sustainability: one to protect the quality of natural resources *and* one to provide for recreational access and experiences (National Park Service, 2006). Laws such as the Wilderness Act of 1964, the National Trails System Act, and the National Forest Management Act of 1976 mandate US federal agencies to plan for and manage visitor use in a way that is compatible with agency's purposes and can be sustained without unacceptable impact to resources. Most agencies acknowledge some impacts to be inevitable, but ask managers to limit impacts to the minimum necessary.

A variety of planning frameworks have been developed to direct and focus decisions regarding impact acceptability and the selection of actions needed to prevent resource impairment. Commonly applied frameworks include Visitor Experience and Resource Protection (VERP) for the National Park Service (Service 1997), Limits of Acceptable Change (LAC) for the U.S. Forest Service (Stankey et al. 1985), and Visitor Use Management (VUM) for six U.S. federal agencies – the Bureau of Land Management, U.S. Forest Service, National Oceanic and Atmospheric Administration, National Park Service, U.S. Army Corps of Engineers, and U.S. Fish and Wildlife Service.

All frameworks tend to focus on prescriptive management objectives that define desired resource and social conditions, selection of indicators and standards of acceptable change, monitoring to compare current conditions to standards, and implementation and evaluation of corrective management actions. Processes are iterative and focus on adaptive management where selected resource standards are monitored for change, and if violated, factors are manipulated to improve conditions. Monitoring programs provide managers with base-line resource condition information from which they can examine long-term trends and evaluate the efficacy of implemented actions (Hadwen et al., 2007; Marion, 1995; Marion, 2016). The field of recreation ecology informs the execution of these planning processes by examining, assessing and monitoring visitor impacts in natural protected areas and their relationships to influential factors to inform protected area management of recreation (Leung and Marion, 2000). Recreation ecology research provides insights regarding factors that influence the deterioration of resources to afford managers the information they need to make effective and defensible decisions. Use-related, environmental, and managerial factors that significantly influence impacts to natural resources can be manipulated through management efforts to avoid or minimize impacts while sustaining high quantities of recreation.

The majority of recreation impacts occur as a result of visitors spending time on or near recreation sites (e.g. campsites or vistas) or visitors traveling between these recreation sites on trail corridors. The sustainability of trails is relatively better understood and the professional management of trails for sustainability has long been recognized. It is general practice for managers to assess their trail systems for sustainability, take action to increase the sustainability of trail alignments, and fix problem areas. Professional construction, maintenance, and management manuals published by private organizations, government agencies, or local municipalities exist for trails both in the United States and internationally (e.g. Hesselbarth et al. 1996, Demrow and Salisbury 1998, Birchard and Proudman 2000, IMBA 2007, Hunt et al. 2015). However, these practices, traditions, and supporting publications have not been developed or applied to campsites.

The term sustainability has been used across many different environmental disciplines and recently was defined for campsites by Eagleston and Marion (2017) as, "…the ability of campsites to accommodate intensive long-term use while remaining in good condition, with minimal maintenance or restoration". The goal of this paper is to increase the understanding of sustainable campsites, specifically answering the research question: which characteristics of the environment and topography most influence the amount of impact on a campsite? Geographic Information Systems (GIS) methods in concert with field assessed data are applied to determine the utility of each in explaining or evaluating campsite size and to increase understanding of their relative influence on areal extent of impacts on individual campsites.

CHAPTER 2: LITERATURE REVIEW

Camping Impacts

Recreation ecology research has consistently shown recreation activities to degrade the biophysical environment, identifying negative impacts to vegetation, soil, water and wildlife (Hammitt et al., 2015; Marion et al., 2016). Common campsite impacts result from trampling or depreciative visitor behavior, and include campsite proliferation, expansion of existing campsites, tree damage, loss and/or compositional change of vegetation cover, soil impacts, pollution of water, and disturbance of wildlife (Leung and Marion, 2004; Marion et al., 2016). This study considers limiting impacts associated directly with trampling, which include vegetation loss, vegetation compositional change, loss of organic matter, and the exposure, compaction, and erosion of soil (Marion et al., 2016).

The morphological characteristics of plants affect their resistance to trampling damage and resilience, which is their capacity to recover following damage. Generally, tall herbs tend to be less resistant and resilient due to their long brittle stems and broad leaves, while graminoids and prostrate herbs exhibit substantially greater trampling resistance and resilience (Cole, 1995a, b; Marion et al., 2016; Pescott and Stewart, 2014; Striker et al., 2011). Both plant resistance and resilience increase with greater sunlight, longer growing seasons, and higher soil fertility and moisture (Cole, 1995b; Cole and Monz, 2003, 2004; Marion et al., 2016). Graminoids are largely shade-intolerant, so these more resistant plants typically grow only in meadows or under open forest canopies. Broad-leafed herbs that tolerate closed forest canopies are predominantly less resistant and resilient to even low levels of trampling (Marion and Cole, 1996). Increased sunlight exposure on campsites due to tree felling by campers facilitates an increase in ground vegetation on campsites, particularly by grasses and sedges (graminoids).

The Relationship between Amount of Use and Level of Impact in Recreation Ecology

Experimental trampling studies indicated that the majority of herbaceous vegetation is lost at low levels of use, with diminishing additional losses as use increases to moderate and high levels (Cole, 1995a; Marion et al., 2016). Empirical studies demonstrated this asymptotic or "curvilinear" relationship for most forms of trampling impact, including the trampling and loss of vegetation and tree seedlings, soil compaction, and the pulverization of organic litter (Figure 1)(Cole and Monz, 2004; Hammitt et al., 2015). Other impacts like loss of organic matter, soil exposure, and root exposure are less curvilinear in nature (Cole and Fichtler, 1983; Coombs, 1976; Marion, 1984).

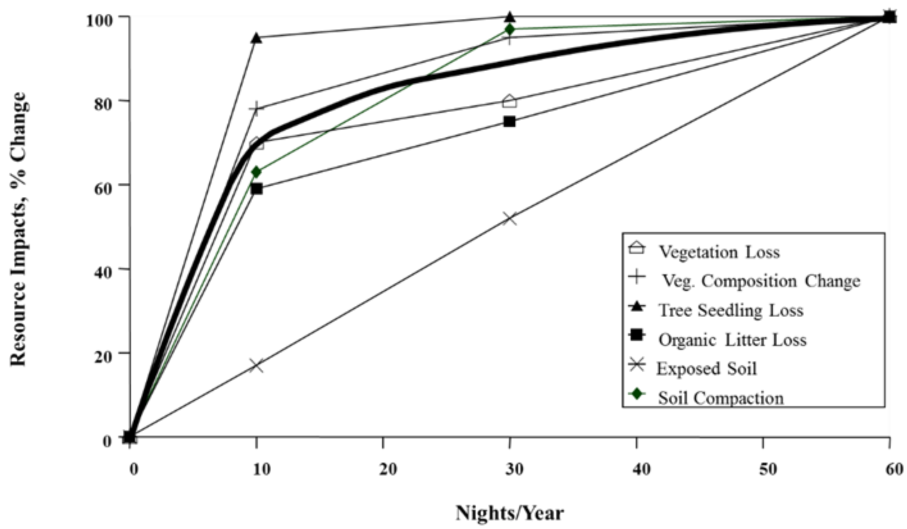


Figure 1. The generalized curvilinear use-impact relationship, depicted by the thick black line, as illustrated by measurements of six impact indicators assessed on campsites in the Boundary Waters Canoe Area Wilderness (Marion, 1984). Resource impacts are expressed as a percentage of change on high use sites.

Hypothetical campsite models developed by Cole (1992), provide further insight into the relative influence of several factors on three core response variables: percent vegetation loss, area of a campsite and area of vegetation loss. Cole's models suggest that increasing use, in the absence of spatial concentration, can have a substantial effect on areal measures of impact, with peripheral and additional off-site vegetation disappearing as campsite boundaries expand but percent measures of vegetation loss, or intensity of impact on the campsite, remaining the same. However, if use increases and camping activities are spatially concentrated, the impacted area remains stable, as trampling impacts are contained within campsite boundaries and percent vegetation loss increases to near maximum levels. Even though percentage of vegetation loss is much greater than in the model where camping activities were *not* spatially concentrated, the total impacted area is still smaller.

Camping Impact Monitoring: Areal Measures of Impact

Several empirical studies have also reported that the areal extent of impact reflected by the expansion in campsite size and proliferation of campsite numbers should be a greater concern than the intensity of localized impacts on indicators (Cole and Marion, 1988; Cole, 1993; Cole and Ferguson, 2009; Cole et al., 2008; Cole and Hall, 1992; Merriam and Peterson, 1983). Commonly used areal measures of impact include the area of vegetation loss and area of exposed soil (Cole, 1989a; Marion, 1995). In a study of three eastern National Park Service units, Cole and Marion (1988) found that high use sites consistently were more impacted than low use sites, but the magnitude of change was relatively small relative to differences in amount of use. Instead, the areal extent of impact was the core difference between high and low use sites (Cole and Marion, 1988). Cole and Hall (1992) report similar conclusions from a long-term meta-study of datasets from the Eagle Cap Wilderness, Bob Marshall Wilderness, and Grand Canyon National Park. They found the slow expansion of campsite boundaries to be the most consistent increase in impact in the two wilderness areas, other impacts remaining relatively stable, with little deterioration over time.

Expansion of site size was also the most substantial finding for eight campsites measured 15 years apart in the Boundary Waters Canoe Area, MN (Merriam and Peterson 1983). They calculated one Boundary Waters Canoe Area Wilderness campsite increased in size by 824% over the course of 15 years. A longer 32-year study of Boundary Water campsites reports generally stable campsite sizes but an increased number of offsite satellite areas (Cole et al. 2008, Eagleston and Marion 2017). Offsite satellite tenting spots almost doubled, while barren core's decreased in size. The BWCAW has management policies that limit expansion, including permits limiting group size, and facilities and site management practices (like installation of anchored fire rings and creation of tent pads) that attract and spatially concentrate camping activities.

Given the tendency for campsites to expand under increasing use, low use campsites are most prone to campsite expansion. At the site-level, increasing use often causes site boundaries and areal measures of camping impact to expand. At the landscape scale, considering cumulative impacts to an defined area, aggregate campsite impacts increase as campsites *proliferate in number* or *expand in size* over time (Cole et al, 2008; Leung and Marion, 2004).

Camping Management Strategies to Reduce Areal Measures of Impact

Recreation ecology studies reveal that resource impacts on campsites occur rapidly, with initial and low levels of use, while recovery rates are exceedingly slow in most environmental settings, particularly where campsite closures are ineffective (Cole et al., 2012; Marion et al., 2016). Managers seeking to address increasing visitation must consider a diverse range of factors that may influence the aggregate measures of camping impact.

Three classes of campsite management strategies are generally employed: "unregulated" (at-large) camping, dispersal or containment (Marion, 2016). When camping is unregulated visitors can camp where they want with few exceptions. Particularly in wilderness, managers prefer to allow visitors the freedom to find and select a campsite of their choice, with minimal interference from regulatory controls. Low impact educational practices are often communicated to influence visitors to select resistant campsites with durable rock or non-vegetated surfaces (e.g., Leave No Trace, www.LNT.edu). However, managers often include some regulations, such as prohibiting camping near water or formal trails in order to protect natural resources or experiential qualities.

Under the dispersed camping class managers encourage the "general dispersal" of campers into less-used areas, avoiding popular trail corridors, lake basins, or attraction features when possible. A purer form of dispersed camping is "pristine site camping," where visitors to low use areas are encouraged to select a camping spot with no prior evidence of use in an area that is unlikely to be found and reused, camping one-to-several nights, at a level that does not create lasting impact (Marion, 2014).

Several recreation ecology research studies have collected campsite data in areas with dispersal-like management strategies and have found programs to be generally unsuccessful (Cole, 2013; Leung et al., 2000). In Jefferson National Forest Wilderness areas where a dispersal camping policy was in place, Leung et al. (2000)found that relatively few visitors practiced dispersed camping. The majority of campsites surveyed were found within sight of the trail; only 20 of 110 sites (18%) were 200ft away from the trail. In another case, Shenandoah National Park, Virginia also employed a dispersal policy throughout their park requiring campers to camp at least 25ft away from water, trails, and other campers. In 1994 the park had 725 campsites, of which 68% were illegal (Reid and Marion, 2004).

Selecting and concentrating camping activities on durable surfaces and restoring the site to natural conditions prior to departure are key elements to success of the strategy. Recreation ecology studies suggest that achieving success with pristine site camping is challenging due to the need for visitors to learn and apply the low impact practices necessary to consistently avoid creating lasting impact and the need for large numbers of resistant camping locations (Cole, 2013; Cole and Benedict, 1983; Leung and Marion, 2000).

Finally, in areas of moderate-to-high visitation, a containment strategy emphasizing “established site camping” or “designated site camping” is often employed (Marion, 2016; Spildie et al., 1999). Managers select only highly sustainable impact-resistant campsites that are not too close to water, formal trails, other campsites, or sensitive species and cultural/historic sites. Visitor freedom to select any of these preferred sites is preserved under the “established site” camping strategy, with managers seeking to close and restore less sustainable or unnecessary campsites. Alternately, even more control over campsite numbers and locations are provided under a “designated site” camping strategy, with sites marked on maps and with signs and often including simple facilities like anchored fire rings. Visitors may only use the designated sites, but they retain the freedom to find and select a preferred site, unless a reservation system is also used, whereby visitors are assigned to specific designated campsites for each night of their visit. A successful containment strategy provides campsites that naturally resist resource impacts and expansion, and that protect experiential qualities by separating visitors from trails and other campsites.

Several studies in the campsite impact literature describe factors that have been found to increase the effectiveness of a containment strategy, or influence the areal extent of campsite impact, including constructing campsites in sloping terrain (Reid and Marion, 2004), manipulating the spatial layout of campsites (Kangas et al., 2007; Marion and Leung, 2004), providing facilities that attract and concentrate use (Marion and Farrell, 2002), development of campsite borders (Leung and Marion, 2004), education with low impact practices (D'Antonio et al., 2013), maintenance to enhance durability or desirability (Cole, 2013), and site restoration and closure (Spildie et al., 1999). Earlier reviews of influential factors are provided by Hammitt et al. (2015), Marion (2003, Appendix 2), and Marion (2016).

Several studies describe the successful application of the containment strategy, including conversion from a general dispersal to established site camping at Shenandoah National Park (Reid and Marion, 2004), and efforts at Delaware Water Gap National Recreation Area to limit the sizes of their designated sites. Marion and Farrell (2002) attributed a substantial reduction in aggregate

Figure 2. Examples of overnight use types. (A) Campsite; (B) Shelter; (C) Side-hill Campsite; (D) Campsite on Road.

camping impact at Isle Royale National Park to the location of campsites in sloping terrain, where small “side-hill” campsites were constructed by excavating upslope soils and depositing them downhill to create small flat tenting sites (Figure 2, letter C). This concept was applied at Annapolis Rocks along the Appalachian Trail in Maryland, shifting camping from visitor-created campsites to new topographically limited side-hill campsites, reducing aggregate impact from 4004 m^2 to 580 m^2 (Daniels and Marion, 2006). In contrast, Cole et al. (2008) found campsite proliferation, measured by number of campsites, within designated site camping areas to be similar to areas with dispersed camping in a Grand Canyon National Park study.

Sites in Isle Royale National Park that contained a picnic table were an average of 12-16 m^2 smaller than sites without tables (Marion and Farrell, 2002). Persistent maintenance efforts that eliminate visual evidence of campsites and improve conditions on legal campsites can help shift use to appropriate areas (Cole, 2013). Success in rehabilitating campsites over 32 years in the Lee Metcalf Wilderness, MT and campsite reduction at Isle Royale National Park were partially attributed to maintenance efforts to enhance use of legal sites and discourage use on inappropriate sites (Cole, 2013; Marion and Farrell, 2002).

Use-related factors that have been shown to influence the variation in campsite size include amount of use, type of use, user behavior, and party size (Cole and Hall, 1992; Hammitt et al., 2015; Liddle, 1997). Management actions that influence use-related factors are often regulatory and include quotas to limit amount of use, restrict use type (e.g., prohibiting livestock), and group size limits. Studies designed to evaluate the efficacy of these actions are rare.

Few studies have explored what characteristics inherent to the environment or topographic factors encourage concentration and limit expansion and proliferation. As previously mentioned, a few studies have documented that shifting campsites to side-hill, topographically-constrained sites and closing campsites in flat areas can substantially reduce aggregate campsite disturbance (Daniels and Marion 2006). Another study employed factor and cluster analyses to discover that large campsites classified as “Extensively Impacted” were frequently located at flatter footslope topographic positions (Leung and Marion, 1999).

Researchers conducting a longitudinal study in the Boundary Water Canoe Area sought to predict campsite expansion potential with ratings based on constraints imposed by topography and vegetation density (Eagleston and Marion, 2017). Authors found the rating to be ineffective as the presence of dense woody vegetation was too ephemeral over longer periods of time due to the effects of fires, insects, and wind storms. These results suggest that camping expansion and off-site camping may better be deterred by sloping topography, rockiness, or shorelines and wet soils (Eagleston and Marion, 2017). The influence of elevation, additional topographic attributes, distances to amenities, forest cover type, and ecoregion have received limited research attention (Leung and Marion, 1999; Marion and Leung, 1997).

While the recreation ecology literature includes numerous studies examining univariate and bivariate analyses of factors that influence campsite sustainability, a comprehensive multiple regression modeling analysis could not be located (Leung and Marion, 2000; Marion, 2016). A significant limitation of the former is that these limited analyses are less able to reveal the "relative" influence of factors. Two studies have applied multivariate factor and cluster analyses with larger numbers of factors but their primary purpose was to classify campsites by types of impact exhibited (Leung and Marion, 1999; Marion and Farrell, 2002; Monz and Twardock, 2010).

Use of GPS and GIS in recreation ecology research

Geographic Information Systems (GIS) and Global Positioning System (GPS) instruments are increasingly being utilized by managers and researchers to inventory resources, monitor changes over time, answer geographic questions, focus planning efforts, and enhance communication with visitors (Landres et al., 2001; Naber and Leung, 2006). GIS are computer software packages designed to aid with the management, visualization, analysis, processing and storage of geographically referenced data along with associated attributes (Goodchild, 2003). GPS devices allow users to collect information on location as vector data: geospatial data represented as points, lines or polygons (Burrough et al., 2015). Use of GIS systems and GPS data in recreation ecology research span the breadth of its capability including mapping of informal trail networks (Barros and Pickering, 2017; Wimpey and Marion, 2011), mapping of campsite locations (Leung et al., 2000), relational analysis using GIS derived variables on trail soil loss (Storck, 2011), examination of visitor movement through protected areas employing agent based modeling (Itami et al., 2003; Lawson et al., 2006), patterns and intensity of visitor use with GPS trackers (Beeco and Brown, 2013; D'Antonio and Monz, 2016; D'Antonio et al., 2013; Monz et al., 2010), analysis of landscape scale impacts of recreation (Barros and Pickering, 2017), and pairing spatial data with social science data to map visitors' perceptions (Kliskey, 1994).

Research integrating GIS into campsite management is limited, with most studies utilizing point data to examine spatial distribution of sites within protected areas. Leung et al. (2000) recorded locational information of campsites to examine their spatial distribution and proximate relationship with other campsites, water sources, trails, and position in the landscape. Spatial visualization of campsite locations revealed tight clusters of campsites and insight into visitor campsite selection preferences (Leung et al., 2000). Other studies use locational information to streamline field data collection and examine impact trends (Sharp et al., 2016) or relocate campsites in longitudinal studies (Reid and Marion, 2004). Carr (2014) uses the locations of campsites and parking to analyzes the effect of distance decay on areal measures of impact. D'Antonio et al. (2013) combined assessments of resource conditions, including GPS-based collection of location and area measurements, with social science data to understand visitors perceptions and exposure to impacts.

Two studies utilized Weighted Overlay techniques to aid in planning and development. Newman et al. (2006) proposed a method utilizing geographic information systems (GIS) to create a campsite sampling strategy. Authors created a camping probability model based on the following spatial factors: distance from trailhead, distance from water, distance visitors tend to travel off trail, and presence of designated no camping zones. Individual probability maps were created for each related to likelihood of finding a campsite based on associated factors (e.g. likelihood of finding a campsite based on distance from trail). Cuirong et al. (2016) uses GIS methods, including Analytic Hierarchy Processes and Weighted Overlay techniques, to produce a campground suitability index map to prioritize and focus campground building efforts.

Only one known study, Graefe and Kim (2014), examines the relative influence of the terrain, as well as field collected variables, on campsite size. Author's goals were to examine the relative influence of several geospatial variables on roadside campsite condition measured by condition class. Geospatial variables input into the model were distances to roads, water, and trails, slope of surrounding terrain, and elevation. Details relating to authors calculations of slope and elevation, nor the methods used to evaluate slope of the surrounding terrain were not specified in this study. 22% of the variation in campsite size was explained through regression with distances from forest roads, major roads, water resources, size of campsite, and slope of the surrounding terrain as significant variables. Lack in clarity about methods make it difficult to follow authors reasoning in conclusions and implications of findings. Particularly, an increase in slope was associated with higher levels of impact, leading to the conclusion that campsites should be located in flatter terrain. However, the influence of slope in concentrating use would result in more intensive trampling over a smaller area, leading to higher levels of exposed soil.

Measuring Campsite Area

Four traditional methods of measuring campsite size exist: a categorical size estimation, the fixed radial transect method (FRTM), the variable radial transect method (VRTM), and the geometric figure method (GFM) (Cole, 1989b; Marion, 1991). Categorical size estimation involves assigning campsites to size categories (Cole, 1989b). Broad categorical rating systems only give a general idea of campsite size, hide measurement error and reduce a manager's ability to detect change in campsite size (Marion, 1991).

To calculate campsite size using the GFM, one or several geometric figures are superimposed on the campsite figure and size is calculated from the summation of all geometric figure areas. Potential sources of error include the application of geometric shapes to complex shapes with irregular boundaries and inaccurate judgement to adequately balance onsite and offsite areas (Marion, 1991). To perform the FRTM, 16 linear transects at set angles are run from an established arbitrary campsite center point to the site's boundary. Distances from the center point to the boundary are recorded and used to determine site size (Cole, 1989b). This method can be inaccurate when the campsite has a complex shape. The VRTM is performed in the same way as the FRTM except instead of a fixed number of transects and set angles these are matched to the unique shape of the campsites (Marion, 1991).

A trial study conducted by (Marion, 1991) to compare tradeoffs of accuracy and precision between the GMF, the FRTM, and the VRTM found the GMF to have the lowest measurement time but intermediate accuracy. Authors noted accuracy is highly dependent on conscientious measurements and the complexity of the shape. The VRTM achieved the highest level of accuracy but took considerably more time to implement.

A new method involving the collection of areas on hand-held GPS devices has emerged in environmental research due to increased accuracy and reduced costs of GPS (Dauwalter et al., 2006; Dauwalter and Rahel, 2011; Lirman et al., 2010). Four known studies in recreation ecology literature have used this method to collect area data, and only two of those collected campsite boundary data (Barros and Pickering, 2017; D'Antonio et al., 2013; Glidden and Lee, 2007; Monz et al., 2010).

Accuracy in collecting campsite size data using the GPS method relies on the abilities of the GPS device to reduce error. GPS data collection involves receivers determining a relative position using the geometry of triangles and measuring distance using the travel time of radio signals from satellites. Errors in GPS data can result from: the satellite clock, the upper atmosphere (ionosphere), the receiver clock, the satellite orbit, the lower atmosphere, and multipath error. Errors resulting from the signal moving through the atmosphere can be minimized through differential correction. Differential correction uses the roving receiver and stationary ground receivers with known locations. Differences between the reported base station receiver locations and the "true" known location is used to estimate the error that has incurred for a specific collection time (Cosentino and Diggle, 1996). Depending on the GPS, differential correction can either occur in the field or is applied after the fact in post-processing (Cosentino and Diggle, 1996).

Most potential for errors can be avoided by user specifications of the positional dilution of precision (PDOP), the number of satellites, and satellite elevation during collection. PDOP is a measure of horizontal (HDOP) and vertical (VDOP) uncertainty derived from the relative position of satellites to each other, or the geometry of the visible satellite arrangement. A smaller PDOP value has more accuracy than a large one. GPS devices have the ability to select optimal satellite configurations to achieve the highest accuracy data, i.e. minimize PDOP. Multipath error occurs when satellite signals bounce off surfaces and reach the receiver at several different times. Some GPS receivers minimize the potential for multipath error by using processes to detect the earliest arriving signal, which is the most direct one (trimble.com).

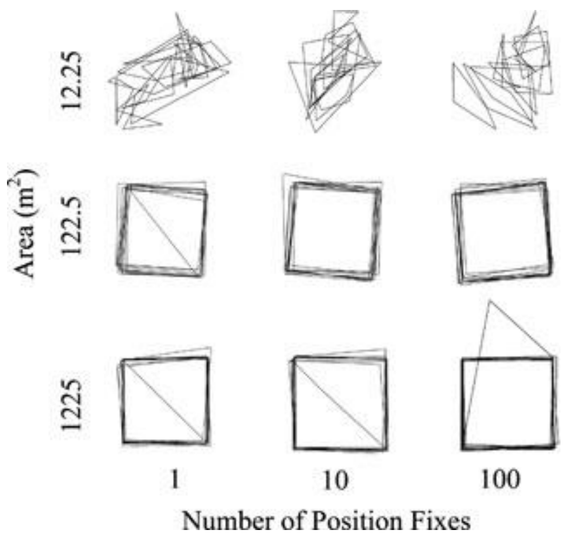
Habitat and population mapping using this method is more frequent in the literature, several studies specifically examining its precision and accuracy of polygon size as compared to measurement with a tape measure (Dauwalter et al., 2006; Dauwalter and Rahel, 2011; Webster and Cardina, 1997). Dauwalter et al. (2006) constructed three polygons at different spatial scales (12.25 m^2, 122.5 m^2, and 1225.0 m^2) and walked the boundaries with a Trimble GeoXT GPS collecting one, ten, and 100 points at each vertices, the latter two averaged. Percent error for small squares were significantly higher than medium or large squares (Figure 3). This and other error observations lead authors to conclude measurements of larger features to have an acceptable amount of error, while area measurements of small features using this method may not be useful (Dauwalter et al., 2006). Error in area measurements ranged from 0.1% to 110.1% but decreased as the area increased. Large, sinuous stream habitat areas mapped with the GPS method were not significantly different than tape measure methods.

Dauwalter and Rahel (2011) compared accuracy and precision of field and GPS methods to known area measurements of habitats with a range of different sizes and shapes. Average error for small features, 2-5 m^2 in size, ranged from 31-83%, while errors for large features, >100 m^2, were less than 10%. Again, area measurements of large features were more precise than small features (Figure 4), and, additionally, precision did not change with changing shape complexity. Authors conclude that this method is effective with features > 50 m^2. Webster and Cardina (1997) reported similar findings of reduced spatial error as area increases: 7-45% error for a 5 m^2 area, 6-15% error for 50 m^2 and 3–6% error for a 500 m^2 area. Results from both Dauwalter et al. (2006) and Webster and Cardina (1997) reveal the utility of averaging position fixes; greater position fixes did not increase precision in test polygons or actual habitat mapping areas.

Neither of the two studies measuring campsite size using this method, D'Antonio et al. (2013) and Glidden and Lee (2007), report measurement error or time involved in collection, making it difficult to compare trade-offs with traditional methods. D'Antonio et al. (2013) clarifies the extent of the GPS method's use stating they only used GPS to measure area where campsites were too large or diffuse to collect efficient radial transect measurements. Dauwalter et al. (2006)'s habitat study report this method being up to 3.3 times faster than using a tape measure, which could be compared to the Geometric Figure Method. Authors of this study, measuring campsites on the AT, estimate ≤ 2 minute to walk the boundaries of a campsite to record size, although terrain or tree cover could occasionally prolong GPS recordings.

LiDAR data

Few recreation ecology campsite studies incorporate LiDAR data and Digital Elevation Models (DEM) into research. LiDAR technology can be used to obtain landscape metrics at a much finer resolution than have been previously available and has successfully been used to characterize landscape and site-specific topographic characteristics (Brubaker et al., 2013). LiDAR has only just begun to be used for recreation ecology research, and so far only for trail erosion studies and sustainable trail design planning (Eagleston and Marion, 2016a; Storck, 2011).



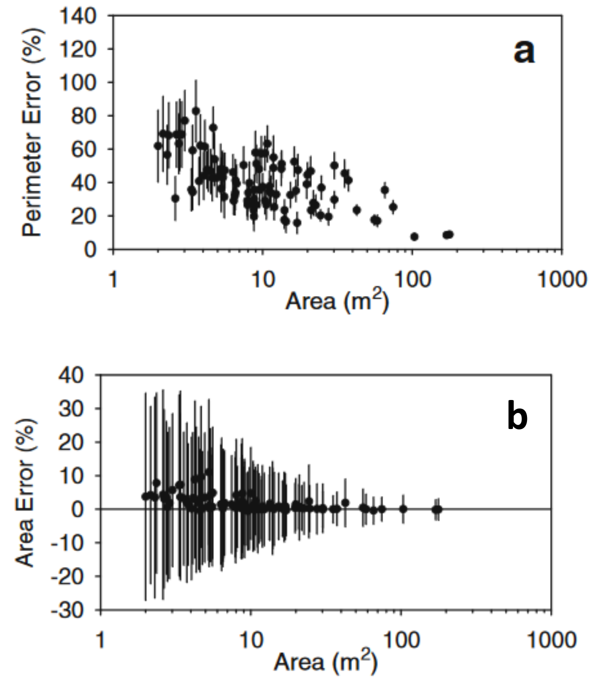


Figure 3. From Dauwalter et al. (2006): "Squares with areas differing by one or two orders of magnitude and mapped with a GPS receiver using a different number of position fixes averaged per polygon vertex (square corner)."

Figure 4. From Dauwalter and Rahel (2011): "Percent error in perimeter length and area of habitat patches in relation to patch area, after GPS error was simulated for digitized [areas]. Circles represent the mean and error bars represent 1 SD of 1,000 simulations per patch".

LiDAR is a remote sensing method that measures distance to a target based on the time for a pulsed laser light to return. A dense point cloud of x, y, and z locations of each return can be filtered through a variety of algorithms to extract points that more accurately represent ground elevations.

While error is inherent in remote sensing data collection, LiDAR data used in this study were tested by sources (Table 5) and meet vertical accuracy requirements defined by the National Standards for Spatial Database Accuracy (NSSDA) and/or assessed and reported in accordance with Guidelines for Digital Elevation Data, developed by the National Digital Elevation Program (NDEP) and subsequently adopted by the American Society for Photogrammetry and Remote Sensing (APPRS). APPRS guidelines require vertical accuracy to be determined by comparing the elevation of LiDAR collected points with the elevation of quality control checkpoints (Equation 1) and is generally reported as $1.96\ RMSE_z$(ASPRS Lidar Committee, 2004).

(1) $RMSE_Z = \sqrt{\frac{\sum Z_{data(i)} - Z_{check(i)}^{\;\;2}}{n}}$

To create a DEM, LiDAR point clouds of elevation data are filtered for ground points and interpolated into a raster representing elevation and topographic characteristics of the bare earth.

Digital Elevation Models

DEMs are digital representations of elevations of the earth's surface and are derived from a variety of remote sensing data. Use of LiDAR data for modeling and predicting environmental phenomena have been used in many ecological applications, including landslide predictions, detection of stream and wetland connectivity and forestry biomass estimations (Jaboyedoff et al., 2012; Lang et al., 2012; Urbazaev et al., 2018). GIS and LiDAR data allow accurate quantitative measures of topography-related metrics surrounding campsites, and evaluations of how they may affect campsite impacts and sustainability. Typical variables calculated from LiDAR data used in such analyses include, for example, slope, curvature, topographic roughness, and aspect.

The final DEM product is a result of a series of processes, each step a chance for error (Bater and Coops, 2009; Fisher and Tate, 2006). Error in DEM generation can be from the generation method of source data, errors from processing and interpolation, and error from characteristics of the terrain (Bater and Coops, 2009; Fisher and Tate, 2006). Accuracy guidelines and standards for DEM interpolation of LiDAR data are also specified by ASPRS guidelines (Abdullah et al., 2015).

We examine the relative influence of many field-collected and GIS-derived variables on two common areal impact indicators used in monitoring studies: campsite size and area of vegetation loss. As the eventual loss of all vegetation and its ability to regenerate is the most severe vegetation-related impact, indicators chosen for monitoring of campsite change often relate to vegetation loss (Hammitt et al., 2015). Measures of vegetation loss that have been used in previous studies include percent absolute vegetation loss (Marion and Farrell 2002), percent relative vegetation loss (Cole, 1982), and area of vegetation loss (Cole and Hall, 1992; Eagleston and Marion, 2017). These measures compare onsite vegetation cover to an adjacent environmentally-similar undisturbed "reference" area but the percentage measurements fail to represent the areal extent of vegetation loss (Cole, 1989a). Area of vegetation loss is a preferred measure because it incorporates areal extent by multiplying absolute loss by campsite size.

CHAPTER 3: STUDY AREA

The Appalachian National Scenic Trail (AT) is a 3526 km continuous footpath stretching from Georgia to Maine traversing the Appalachian Mountain range through 14 states, 6 National Park Service units, 8 National Forests, and a suite of more than 80 state and local jurisdictions (National Park Service, 2008). It is estimated that the AT receives two to three million visitors per year, including day hikes, weekend camping trips, section-hikes, and thru-hikes of the entire trail in one season (Appalachian Trail Conservancy, 2018). The number of hikers registering to complete a thru-hike has increased 210% in just the last three years, from 1,927 in 2015 to 4,050 in 2017, and further increases are expected (Appalachian Trail Conservancy, 2017). While the number of thru-hikers is a small proportion of overall use, their increasing use is concerning due to the large number of campsites needed along the trail to accommodate their increasing numbers. Additionally, there are several hundred AT trailheads accessible within a day's drive by over half the U.S. population and the majority of AT visitation is comprised of day-hikes and short backpacking trips (Zarnoch et al., 2011).

Conceived in 1921, completed in 1937, and designated as the first National Scenic Trail in 1968, trail-wide AT management responsibilities are based on a unique partnership between its original caregivers, the Appalachian Trail Conservancy (ATC), and the National Park Service's Appalachian Trail Park Office (APPA). Trail maintenance and management functions are delegated to 31 volunteer trail clubs, with guidance from the ATC and collaboration with APPA and federal, state, and local land managers (Appalachian Trail Conservancy, 2009).

Camping management along the AT is diverse, with "at-large" unregulated camping, dispersed camping, established and designated site camping at approximately 4000 sites, and camping at 280 shelters spaced approximately thirteen kilometers apart (appalachiantrail.org, National Park Service, 2008). A survey of AT visitors found that 56% of the overnight visitors stayed in shelters, 12% camped near shelters, 23% stayed at designated campsites or tent sites, and 9% camped elsewhere along the AT (Manning et al., 2000). Camping regulations and guidance vary considerably along the AT due to the numerous management agencies involved and historical precedence (appalachiantrail.org), but the land managers and volunteers have adopted consistent low impact outdoor practices advocated by the national Leave No Trace program.

The AT corridor connects a variety of land designations including federally designated Wilderness, backcountry, rural agricultural areas, and very accessible front country. The 101,171 ha encompassed in the protected corridor connects a diverse array of ecologically and culturally significant resources. It's length and orientation across exceptionally diverse geologic, latitudinal, elevation and moisture gradients support an incredible diversity in flora, fauna, and habitats that also protect watersheds, which provide significant ecosystem services (National Park Service, 2008). The AT traverses five major geologic subprovinces of the Appalachian Mountains, which include 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 (National Park Service, 2008).

The AT corridor provides critical habitat for nine federally endangered and threatened species and over 80 globally rare plant community types, including two of the most endangered U.S. ecosystems: red spruce/Fraser fir forest and the Southern Appalachian Mountain bogs (National Parks Conservation Association, 2010). The AT 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 (National Park Service, 2008). While predominantly forested, the AT also traverses some grassy balds and treeless high-elevation vegetation communities (elevations range from 38-2025 m).

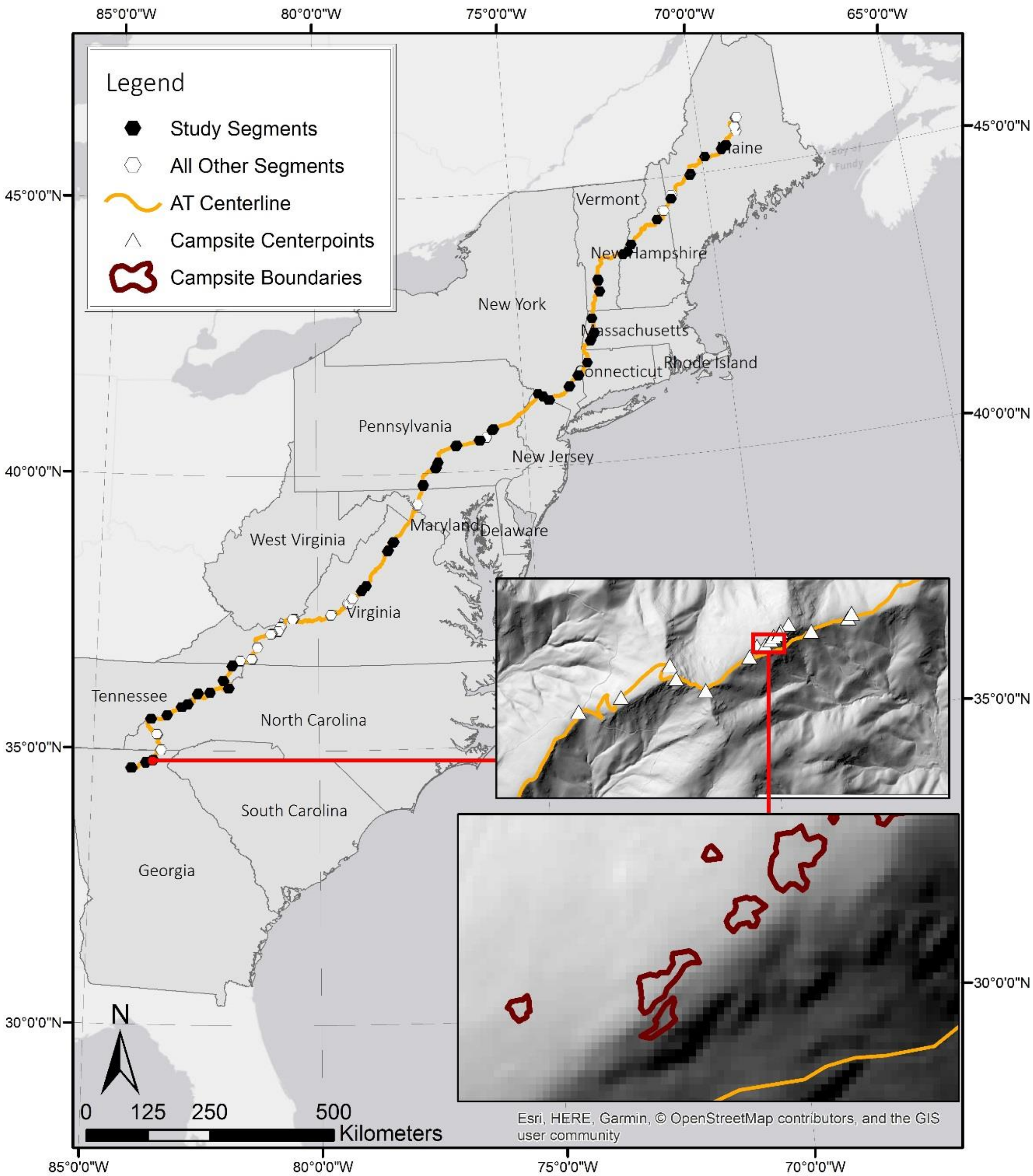


Figure 5. The location of study segments and an example of campsite polygons along the Appalachian Trail. While data was collected for 63 5k segments, only the segments with overlapping LiDAR data were used in this study (Black Hexagons).

CHAPTER 4: METHODS

Sample Selection

Along the AT a random but spatially-balanced 9% sample was achieved using the Environmental Protection Agency's Generalized Random Tessellation Stratified (GRTS) sample design (Stevens and Olsen, 2004). Each of the 63 sampled five- km segments were carefully searched within 150m of the tread by following all informal (visitor-created) trails to locate and assess all disturbed areas used as overnight campsites, including in the vicinity of shelters. Day-use vista sites and resting spots along the trail with no evidence of overnight use were also assessed but are not included in this paper.

Field Procedures

504 campsites were located and assessed within the study segment (207 ultimately used in analysis). Taking into account the breadth of data needing to be collected for this study (a 10% sample of the 3,526 km AT of both trail and campsite measurements) a rapid assessment of campsite size was required. These campsites' boundaries and center points were recorded using a Trimble GeoXT to identify campsite locations and compute campsite size, 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 the campsite. While authors were not aware of accuracy studies involving the GPS method for campsite size measurements at the time, inadequate accuracy of smaller campsite areas were suspected. To mitigate, campsite polygons were visually checked for accurate representations of shape and area on the receiver in the field. Very small campsite sizes or an inability to yield an accurate reading on the GPS, were recorded using the GFM. GPS data in this study was collected with PDOP specified at ≤ 6. If topography or forest cover prevented data collection from moving forward, the maximum allowable PDOP was increased. The GPS receiver used in this study minimizes the potential for multipath error by using processes to detect the earliest arriving signal. Site boundaries were identified by pronounced and visually obvious changes in a combination of vegetation cover, vegetation height/disturbance, vegetation composition, and surface organic litter caused from visitor use (Marion, 1995).

Within each campsite boundary, a midpoint 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).

Other characteristics recorded in the field include use level, campsite type, site expansion potential, tree canopy cover, offsite woody vegetation density, and offsite topographic roughness. The variety of access points, management entities and length of the AT made estimating use levels based on quotas or permits impossible for this study. Additionally finding a knowledgeable person to estimate use level in the field was logistically impractical. To estimate use level, field staff instead used other cues such as knowledge of area, observation of local hikers, accessibility, or nearby amenities. Additionally, prior research findings, from both empirical and experimental studies, describing how vegetation cover and the exposure of soil change with increasing use was used to estimate use level in the field. In particular, soil exposure has a linear relationship to increasing use, with no soil exposure at low use levels, slight at moderate and severe at high levels of use(Cole and Fichtler, 1983; Coombs, 1976; Marion, 1984).

Campsite type refers to the following categories: campsite (C), shelter site (S), side-hill campsite (SHC), and campsites on roads (CR) (Figure 2). Side-hill sites are those located in sloping terrain that involved cut-and-fill excavations of soil to create small level campsites. Campsites on roads are campsites that formed on forest roads that are no longer in use. Site expansion potential in three categories (poor, moderate, high) refers to how easily a campsite could expand due to features in the immediate offsite area, including slope, rockiness, vegetation density, and/or drainage (Eagleston and Marion, 2017). 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 the adjacent offsite vegetation density or landscape roughness would discourage campers from expanding the campsite boundaries.

GIS Variables

GPS data collected in the field were imported, differentially corrected using Trimble’s Pathfinder Office software and base station data from the nearest available Continuously Operating Reference

Station (CORS), 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 campsite polygon to the averaged center point. When the vertices of a polygon were clearly in error, either too distant from other points or creating crossed boundary lines, the vertices were moved to create a shape that more accurately represented the campsite. Professional judgement and campsite photos were used to aid the editing process. When the averaged horizontal error for polygons exceeded 2 m the campsites were excluded from 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 AT segments. 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 AT was not possible due to differing collection sensors, vendors, and processing methods. All LiDAR data and LiDAR data derived DEMs meet or exceed standardized quality and validation methods defined by the National Standards for Spatial Database Accuracy (NSSDA) and/or assessed and reported in accordance with Guidelines for Digital Elevation Data, developed by the National Digital Elevation Program (NDEP) and subsequently adopted by the American Society for Photogrammetry and Remote Sensing (APPRS). DEM resolutions included 19 study segments at <1 m, 12 at 1 m, 8 at 2 m, and 3 at 3 m. Additional LiDAR data specifications are provided in Appendix 1.

Terrain characteristics representing variables that could influence campsite expansion were computed in ArcMap 10.5.1 software using the bare earth DEM for each segment. These variables include measurements of topographic slope, curvature, terrain roughness, and topographic position.

Percent slope was computed using the Slope tool in the Spatial Analyst Extension in ArcMap 10.5.1. Terrain roughness was calculated using three methods: standard deviation of elevation, standard deviation of slope, and a terrain ruggedness index. Standard deviation of elevation and slope was measured using the focal statistics tool in ArcMap over a 5 m by 5 m moving window of the elevation and percent slope layers, respectively. The Terrain Ruggedness Index (TRI), created by Riley et al. (1999), is used to characterize terrain heterogeneity and has been applied in other ecological studies on soils, vegetation, and habitat mapping (e.g. Lindsay et al., 2015; Sharma et al., 2015; Tien Bui et al., 2017). Equation (2) was used to compute TRI, where max and min are the largest and smallest values of a specified neighborhood surrounding the cell. Focal statistics was used to compute maximum and minimum values of a 15 m by 15 m neighborhood, the approximate size of an average campsite, surrounding a cell.

$$(2) \quad TRI = \sqrt{|max^2 - min^2|}$$

Campsites may differ in size based on their position in the landscape (e.g. valley, ridge, flat area, mid-slope). The Topographic Position Index was used to represent relative position in the landscape using an algorithm presented by Weiss (2001), by comparing the elevation of a raster cell to the mean elevations of cells surrounding it.

$$(3) \quad TPI = \frac{dem - focalmean(dem, annulus, irad, orad)}{focalStDev(dem, annulus, irad, orad)}$$

[scalefactor = outer radius in map units, irad = inner radius of annulus in cells, orad = outer radius of annulus in cells]

TPI can be computed at different scales by manipulating the size of annulus used in analysis. Different scales may give insight into position in the overall landscape vs. position at a smaller scale. Three TPI maps were computed at different scales: one at the landscape scale using an inner radius of 40 m and outer radius of 80 m; one at a mid-scale using an inner radius of 20 m and outer radius of 40 m; and one at a micro-scale with an inner radius of 5 m and an outer radius of 10 m. TPI breakpoints were reclassified based on values and slope into land position categories defined by Weiss (2001).

Ten different buffers, from which statistics could be extracted, were created to characterize the area directly surrounding campsites that may influence the location or expansion of campsite boundaries. To create this analysis buffer, campsite polygons created from collected campsite data along the AT were buffered by 10 m, 20 m and 30 m, and the *Erase* tool was used to remove the existing campsite footprint from analysis (Figure 6). A second type of buffer was also created under an assumption that campsite boundaries could have expanded to the point where topographic

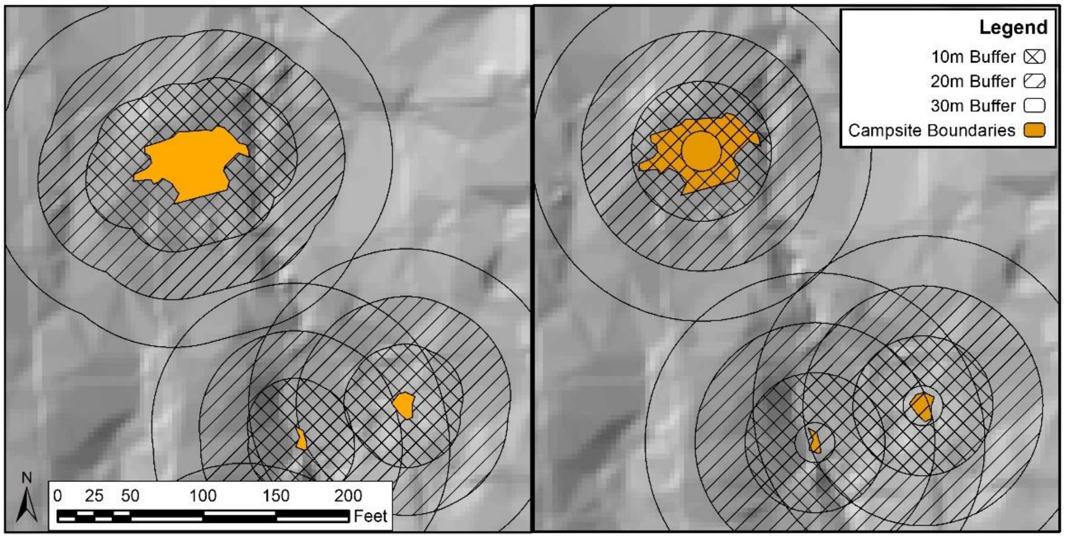


Figure 6. Example of analysis buffers. 5 different kinds of buffers per campsite: from campsite boundary out 10, 20, and 30m and from edge of 10 to 20 and 20 to 30.

characteristics have already discouraged further expansion. To explore this, campsite polygons of the median campsite size (~152 m^2) from our dataset were created and placed on campsite center points. These new median campsites were buffered: at 10 m, 20 m, and 30 m with the median campsite footprint erased (Figure 6). The objective is to examine topographic attributes that *encouraged* or *discouraged* further expansion from the median size, resulting in the campsite's current size.

The Zonal Statistics tool was used to extract mean and median (where appropriate) statistics from the created raster layers within these buffers. Slope was additionally split into three slope categories: 0-8%, 9-17%, >17% and the percent of the buffer that contained each of these categories was computed. 17% was chosen as the upper slope threshold based on observations by Daniels and Marion (2006) noting that constructed side-hill campsites in 10-15% sloping terrain expanded slightly after one year of use, adding 2% to account for slight error in LiDAR derived DEMs.

Distance measurements were calculated as Euclidean distances in ArcMap with the *Generate Near Table* tool. Spatial data containing information on landform type, ecozones, and forest types were downloaded from epa.gov. The National Land Cover Database (NLCD), a Landsat-based land cover database, provides broad descriptions of the land surface, e.g. classifications such as deciduous forest and developed open space, and was downloaded from mrlc.gov.

Data Analysis

The dependent (response) variables used in these regression models include two different areal measures of camping impact: campsite size and area of vegetation loss. Estimates of exposed soil was incorporated into use level estimates and was therefore not used as a dependent variable in regressions. However, exposed soil measurements are examined in relation to certain key factors in later analysis. Campsite areas were calculated using ArcMap. Area of vegetation loss was calculated as the product of absolute loss and campsite size and area of exposed soil was calculated as the product of percentage of exposed soil within site boundaries and campsite size (Equations 4 & 5) (Cole, 1989a).

$$(4) \quad Area\ of\ Veg\ Loss = \left(\frac{\%\ OFFsite\ vegetation\ cover - \%\ ONsite\ vegetation\ cover}{100}\right) * total\ area$$

$$(5) \quad Area\ of\ Exposed\ Soil = \left(\frac{\%\ exposed\ soil}{100}\right) * total\ area$$

Data were input into spreadsheets, checked and cleaned for errors, and imported into the JMP statistical package for analyses. Only data with overlapping LiDAR coverage were used in subsequent analyses (N=207). To reduce instances of covariance, standard least squares regression using the minimum Bayesian information criterion (BIC) was performed between the dependent variables and variables that were created using alternative computational methods (e.g. slope surrounding campsites was measured as a mean, median, or percent of a buffer in a certain slope class). In these cases, only one variable was chosen and entered into the variable selection process.

The Least Absolute Shrinkage and Selection Operator (LASSO) penalized regression procedure with 5-fold cross-verification modeling was used to identify key predictors from 25 different candidate independent variables (Tibshirani, 1996). By penalizing the absolute size of the coefficients, or constraining the sum of the absolute value of coefficients, LASSO shrinks weak regression coefficients to zero, while retaining the stronger, better performing variables. Variables selected through LASSO were used in Ordinary Least Squares (OLS) regression. To avoid overfitting and to achieve a parsimonious model, the regression models were then simplified by removing variables with low significance, i.e. $p>0.05$ in succession from largest to smallest until only significant coefficients remained. To fulfill the normality assumption of regression, a Boxcox transformation was applied to both dependent variables. To examine the individual influence of key variables, the Kruskal-Wallis rank sum test and the Steel-Dwass method were applied. These non-parametric tests were used due to violation of the normality assumption.

Table 1. Variables analyzed for relative influence on areal measures of campsite impacts.

Categorical Variables	**Levels**	**Source**
Use Level	Low, Medium, High	Field Collected
Campsite type	Shelter, Campsite, Side-hill campsite, Campsites on road	Field Collected
Topographic Roughness Offsite	Low, Medium, High	Field Collected
Campsite Expansion Potential	Low, Medium, High	Field Collected
Density of offsite woody vegetation	Low, Medium, High	Field Collected
Dominant offsite vegetation	Grass, Herbs, Moss	Field Collected
Aspect	North, South, East, West	GIS calculation
National Land Cover Database Classification	Developed, deciduous forest, evergreen forest, mixed forest, shrub/scrub, woody wetlands	mrls.gov
Landform type (8 categories)	(1)Broad-moderately dissected valley-karstic southern half (2)High mountains (3)Long narrow ridges, broad narrow valleys karst; Steep ridges (4)Low mountains (5)Low mountains, ice scoured (6)Open high hills; open hills, steep sided valleys (7)Open low mountains (8)Open low mountains, ice scoured	epa.gov
Major Forest Cover Type (4 categories)	(1)Chestnut Oak FA; Chestnut Oak-Scarlet Oak (Black Oak) FA (2)Hemlock-White Pine/Red Oak-White Pine/Sugar Maple-Chinquapin Oak Forest (3)Oak-Heath dry forest (4)Red Spruce-Balsam Fir Forest; Red Spruce-Balsam Fir/Sugar Maple-Birch-Beech Forest; Sugar Maple-Birch-Beech Forest; Sugar Maple-Birch-Beech/ Red Spruce-Balsam Fir Forest.	epa.gov
Level 4 EPA ecoregion category (10 categories)	(1)Taconic Mountains; Green Mountains/Berkshire Highlands; Lower Berkshire Hills; Vermont Piedmont (2)Glaciated Reading Prong/Hudson Highlands (3)Upper Montane/Alpine Zone (4)Quebec/New England Boundary Mountains (5)Northern Igneous Ridges (6)Northern Sedimentary and Metasedimentary Ridges (7)Southern Crystalline Ridges and Mountains (8)Southern Sedimentary Ridges; Southern Metasedimentary Mountains (9)High Mountains (10)Northern Limestone/Dolomite Valleys and Low Rolling Hills; Northern Sandstone Ridges; Southern Limestone/Dolomite Valleys and Low Rolling Hills	epa.gov
Distance from campsite to: shelter, privy, water, vista, parking, AT tread, other campsite	Linear distance between features: 0-0.2, 0.2-0.4, 0.4-0.6, 0.6-0.8, 0.8+ km	GIS calculation
Topographic Position Index at 3 different scales	Ridge, upper slope, flat, middle slope, lower slope, valley	GIS calculation
Terrain Ruggedness index	Level, nearly level, slightly rugged, intermediately rugged, moderately rugged, highly rugged, extremely rugged	GIS calculation
Continuous Variables	**Measurements**	
Tree Canopy Cover	% tree canopy cover over campsites. (0-5%, 6-25% 26-50%, 51-75%, 76-95%, 96-100%)	Field Collected
Elevation	Elevation at campsite	GIS calculation
Distance from campsite to: shelter, privy, water, vista, parking, AT tread, other campsite	Linear distance between features	GIS calculation
Slope	1) Median slope 2) Mean slope 3) % of buffer that is 0-8% slope 4) % of buffer that is 8-17% slope 5) % of buffer that is >17% slope	GIS calculation

CHAPTER 5: RESULTS

This section begins with results from extensive regression modeling focused on identifying variables with the greatest influence on campsite size and area of vegetation loss. A comprehensive and diverse array of potential variables were examined. Following presentation of findings from the final models, we describe the influence of key variables (those managers have the ability to manipulate). Additional tables and statistical tests provide a more thorough description of their influence.

Regressions

Influences from attributes on a local scale and ecological attributes on the scale of ecoregions were significant predictors of variation in areal measures of campsite impact. Table 2 presents results from the final regression models, where the coefficient of determination (R^2) represents the proportion of variation explained in the three areal measures of camping impact by each model's set of significant independent variables. Models explained 64% of the variation in campsite size and 61% of the variation in the area of vegetation loss. The best LiDAR-derived measure of topography selected in the modeling was terrain slope: percent of the 10 m median campsite size buffer occupied by greater than 17% slopes. This slope measurement was the most statistically significant ($p<.001$) in the campsite size model, though still highly significant in explaining variation in the area of vegetation loss model. These models predict that for every added percentage of the buffer that is greater than 17% slope, campsite size will decrease by 0.8 m^2 and the area of vegetation lost will decrease by 0.2 m^2.

Use level and overnight site type were also highly significant in both models, ($p<.001$) (Table 2). High use levels and shelter sites generally have a large positive influence on areal measures and low use levels and side-hill campsites have a large negative influence.

Parameter estimates for campsites between 0.6-0.8 km from a parking area are statistically significant and have a large positive association with both dependent variables (Table 2). Tree canopy cover was a significant variable in the area of vegetation loss model, with $p<.001$. The model predicts that for every percent increase in campsite tree canopy cover the area of vegetation loss increases by 0.4 m^2. Offsite rugosity is significant in explaining variation in campsite size: increases in rugosity in the offsite area equates to a smaller campsite size.

Table 2. Results from the chosen regression models for the three dependent variables: site size, area of vegetation lost, and area of exposed soil.

Variables	Categorical Levels	Regression models Site Size (m^2)	Regression models Area Veg Loss (m^2)
Boxcox Transformation		0.097	0.305
Use Level		**57.2 (<.001)*[1]**	**35.6 (<.001)***
	Low	-51.5 (<.001)*[2]	-22.7 (<.001)*
	Medium	-2.3 (0.613)	-1.1 (0.668)
	High	53.9 (<.001)*	23.8 (<.001)*
Overnight Site Type		**9.3 (<.001)***	**9.9 (<.001)***
	Shelter	40.1 (<.001)*	24.9 (<.001)*
	Campsite	-9.8 (0.245)	-7.4 (0.120)
	SHC	-51.6 (<.001)*	-26.8 (<.001)*
	CR	21.3 (0.217)	9.3 (0.322)
>17% Slope		**20.3 (<.001)***	**8.1 (0.005)***
		-0.6 (<.001)*	-0.2 (0.005)*
Tree Canopy Cover (%)			**27.1 (<.001)***
			0.4 (<.001)*
Distance to Parking Categories		**3.2 (0.014)***	**4.2 (0.003)***
	0 – 0.2 km	-22.9 (0.149)	-5.4 (0.534)
	0.2 – 0.4 km	1.6 (0.938)	-0.3 (0.980)
	0.4 – 0.6 km	-20.3 (0.149)	-14.4 (0.061)
	0.6 - .8 km	31.4 (0.002)*	19.6 (<.001)*
	> .8 km	10.2 (0.210)	0.5 (0.908)
Offsite Rugosity		**4.1 (0.019)***	
	Low	6.7 (0.292)	
	Medium	13.7 (0.021)*	
	High	-20.3 (0.007)*	
Level 4 EPA Ecozones		**2.5 (0.013)***	**4.1 (<.001)***
	1. Taconic Mountains; Green Mountains/Berkshire Highlands; Lower Berkshire Hills; Vermont Piedmont	-0.7 (0.967)	12.3 (0.172)
	2. Glaciated Reading Prong/Hudson Highlands	13.8 (0.221)	-4.8 (0.450)
	3. Upper Montane/Alpine Zone	-35.3 (0.006)*	-18.2 (0.007)*
	4. Quebec/New England Boundary Mountains	-17.2 (0.357)	-18.9 (0.077)
	5. Northern Igneous Ridges	7.6 (0.489)	13.2 (0.031)*
	6. Southern Crystalline Ridges and Mountains	25.4 (0.007)*	18.8 (<.001)*
	7. Southern Sedimentary Ridges; Southern Metasedimentary Mountains	15.4 (0.079)	5.9 (0.211)
	8. High Mountains	-16.4 (0.283)	-5.6 (0.490)
	9. Northern Limestone/Dolomite Valleys and Low Rolling Hills; Northern Sandstone Ridges; Southern Limestone/Dolomite Valleys and Low Rolling Hills	7.2 (0.433)	-2.6 (0.593)
Constant		313.8	46.8
R^2		0.64	0.61
F-stat		16.6	14.8
RMSE		503.5	274.6

1 – Overall effect tests are in bold and in the format: F-stat (p-value)
2 – Expanded estimates, in the format: parameter estimate (p-value)

The ecoregion in which a campsite occurs was consistently significant in explaining variation across both dependent variables, however only a few of the parameter estimates for the expanded levels were significant (Table 2). Ecoregion had the strongest effect on vegetation measures. The Upper Montane/Alpine Zone ecoregion has a significantly negative parameter estimate and the Southern Crystalline Ridges and Mountains ecoregion has a significantly positive parameter estimate for all dependent variables.

Table 3. Mean values for the dependent variables and three related variables for key variables from the regression modeling. Statistical significance was evaluated with Kruskal-Wallis Chi-square tests and the Steel-Dwass method for multiple comparisons.

		N	Area of Campsite (m^2)	Area of Vegetation Loss (m^2)	Area of Exposed soil (m^2)	Vegetation Cover (%)	Vegetation Loss (%)	Exposed Soil (%)
Use Level	Low	47	35[1] A[2]	19 A	6 A **	27 A	49 A	13 A**
	Medium	84	79 B	40 B	23 B	24 A	56 A	29 B
	High	76	207 C	120 C	99 C	21 A	59 A	49 C
Chi-square/ p-value			74.0 / <.0001	53.0 / <.0001	86.4 / <.0001	1.5 / 0.4804	2.6 / 0.2711	49.0 / <.0001
Overnight Site Type	Campsite	171	105 A	57 A	38 A	26 A	55 A	30 A
	Shelter	19	275 B	160 B	156 B	22 A	54 A	50 B
	SHC	12	34 C	16 A	11 A	5 B	58 A	49 A B
	CR	5	102 A B C	73 A B	42 A B	8 A B	73 A	45 A B
Chi-square/ p-value			28.4 / <.0001	13.7 / 0.0033	20.5 / <.0001	14.2 / 0.0027	2.3 / 0.5120	12.7 / 0.0053
Tree Canopy Cover Categories	0 – 5%	11	92 A	7 A	27 A	58 A	19 A	27 A
	6 – 25%	12	137 A	72 A B	55 A	34 A B	41 A B	29 A
	25 – 50%	12	163 A	98 A B	42 A	32 A B	49 A B	20 A
	50 – 75%	28	130 A	69 B	53 A	28 A B	52 B	23 A
	75 – 95%	110	120 A	70 B	52 A	18 B	62 B	39 A
	95 – 100%	34	75 A	46 B	32 A	20 B	56 B	28 A
Chi-square/ p-value			6.4 / 0.2716	23.7 / 0.0002	7.8 / 0.1653	25.6 / 0.0001	26.1 / <.0001	10.2 / 0.0690
Proportion of Buffer >17%	0 – 25%	73	159 A	85 A	61 A	27 A	58 A B	30 A
	26 – 50%	45	109 A B	53 A B	34 A	28 A	48 A	26 A
	51 – 75%	43	96 B	56 A B	45 A	25 A	49 A B	32 A
	76 – 100%	46	73 B	51 B	40 A	14 B	65 B	45 A
Chi-squared/ p-value			21.6 / <.0001	13.2 / 0.0043	3.2 / 0.3604	12.1 / 0.0072	11.1 / 0.0112	8.0 / 0.0464

1 – Numbers presented are means

2 - Means that do not share the same letter are significantly different.

** - Differences between means involving exposed soil by use levels should be considered with caution. Use level estimates were determined using knowledge of the relationship between percent exposed soil and use level derived from empirical and experimental studies.

Key Variables

The influence of key variables is further examined in Table 3, which presents results from Kruskal-Wallis tests for significant differences on dependent variables by a categorical independent variable, the key variables The Steel-dwass method was used for multiple comparisons across levels of categorical variables.

Use Level

A Kruskal-Wallis test applied to examine if there were differences in mean values in dependent and related variables between use levels yielded significant results for all except percent vegetation cover (Table 3). The Steel-Dwass post hoc nonparametric comparison for all pairs of means revealed that all use levels differ significantly from each other at $p<.05$ for campsite size, area of vegetation lost, area of exposed soil, and percent exposed soil. Means for all areal measures and percent exposed soil increased sequentially from low to high use. Differences between percent vegetation loss at the low and high level were significant, low use levels having significantly lower vegetation loss than high use levels. Differences between means involving exposed soil by use levels should be considered with caution. Use level estimates were determined using knowledge of the relationship between percent exposed soil and use level derived from empirical and experimental studies.

Overnight Site Type

The Kruskal-Wallis test revealed statistically significant individual effects of overnight use types on the mean values for all impact indicators except percent vegetation loss (Table 3). Mean percent vegetation measurements for side-hill sites reveal low vegetation cover and high vegetation loss. However, the Steel-Dwass method for multiple comparisons indicate statistically smaller areal measures of impact for side-hill campsites compared to shelters and campsites; areal means are consistently much lower on side-hill sites and higher on shelter sites compared to other use types. Mean percent measures of exposed soil are higher for shelters and side-hill sites compared to campsites. Percent vegetation loss is not significantly different between any overnight site types.

Tree Canopy Cover

Differences in tree canopy cover did not significantly affect campsite size or percent exposed soil (Table 3). However, vegetation measures, both areal and percent, were significantly related to percent tree canopy cover. Results show significantly higher percent vegetation cover on campsites with 0-5% tree canopy cover (95-100% sunlight) compared to campsites with 75-95% tree canopy cover and 95-100% tree canopy cover.

Slope

The proportion of area surrounding the campsite that is greater than 17% slope was split into four categories: 0-25% of the buffer occupied by sloping terrain, 26-50%, 51-75%, and 76-100%. Slope surrounding campsites was significant to differences in campsite size, area of vegetation lost, percent vegetation onsite, percent vegetation lost, and percent exposed soil (Table 3). Campsites with a higher proportion of sloping terrain surrounding the campsite, 51-75% and 75-100%, are significantly smaller than those where only 0-25% of the terrain is sloping (96 m^2 and 73 m^2 vs. 159 m^2). Differences in area of vegetation loss were significant only between the lowest and highest categories and differences in area of exposed soil were not significantly different between slope categories. However, these areal measures decrease sequentially as the proportion of area surrounding campsites with sloping terrain increases.

The concentration effect of sloping terrain is apparent in how percent measures of vegetation and exposed soil reacted. Percent vegetation cover is significantly lower on campsites with the highest proportion of surrounding sloping terrain, 75-100%, compared to campsites with the lowest, 0-25%. Percent vegetation loss is highest on campsites in the most sloping terrain, however this is only significantly different than campsites with 26-50% surrounding sloping terrain. Percent exposed soil is not significantly different across surrounding sloping terrain categories, though campsites with 75-100% sloping terrain have the highest mean percent exposed soil (45%).

CHAPTER 6: DISCUSSION

Understaffed and underfunded, recreation managers, both in the United States and abroad, have identified the need to increase the efficiency and sustainability of their recreational infrastructure to protect natural conditions and provide high-quality recreational experiences. Several long-term monitoring studies indicate the expansion and proliferation of individual campsites, and growth of overall camping-related impacts, to be the most substantial managerial concerns, rather than the intensity of site-level impacts. Campsite sustainability should therefore focus on a campsite's ability to accommodate intensive long-term use while remaining in stable condition and size, with minimal maintenance or restoration needs (Eagleston and Marion, 2017). This study aimed at enhancing an understanding of factors that influence the ecological sustainability of campsites. Extensive modeling with linear regression variable selection methods indicated four variables that significantly explain variation in the areal extent of campsite impacts that can be manipulated by managers: use level, overnight site type, slope, and topographic roughness.

The Influence of Use Level

Hypothetical models suggest use level may be very important in explaining variation in campsite size, especially if we are trying to examine the influence of concentration factors, and therefore is an important component of the regression models. Intuitively, low use campsites are not getting enough use to expand and thus expansion will not react to factors that may influence concentration, like topography. However, as mentioned previously, the estimated level of use on each of the campsites was a subjective estimation, and bias could be present in estimates. As such, management actions should not be inferred from the results of use level in this analysis.

Use level is the most significant explanatory variable for all three dependent variables in the chosen models (Table 2). This result is consistent with previously described hypothetical campsite models by Cole (1992) and spatial patterns of campsite impacts on experimental campsites in the Wind River Mountains, WY (Cole and Monz, 2004). In this experimental study, campers were instructed to concentrate activities towards the center of a previously undisturbed campsite for one and four nights a year over a three-year period. From initial to intermediate levels of campsite use, size increases rapidly and then levels off. If use or group size were to increase on a particular campsite in the absence of a concentration factor, boundaries will expand, eventually reaching a new equilibrium.

Other studies found no significant relationship between amount of use and extent of impact (Cole, 1986; Eagleston and Marion, 2016b; Kangas et al., 2007). This may result from the difficulty in capturing accurate use estimates, the variation in methodologies applied, or the effect of management strategies to concentrate use, such as anchored fire rings. Reliable and accurate use data is a perennial problem for campsite studies in wildland settings (Cole, 1986; Cole and Marion, 1988; Eagleston and Marion, 2017). For example, Cole (1986) assigned use levels to campsites based on the use level of lake basins because site-specific data were unavailable. In another study, experienced rangers and limited use data from campsite registration boxes informed use levels (Cole and Marion, 1988). While statistical significance has varied across studies, generally site size increases substantially from low to moderate use, often, but not always, with smaller increases in size from moderate to high use (Cole and Marion, 1988).

Our findings indicate that the typical A.T. low-use campsite has a mean size of 40 m^2, with vegetation loss over an area of 18 m^2 and soil exposure of 5 m^2 (Table 3). The typical high use A.T. campsite is 208 m^2, with vegetation lost over 116 m^2 and soil exposed over 92 m^2 (Table 3). As mentioned in the literature review, the use-impact relationship suggests that aggregate camping impact would be substantially reduced for these and many moderate use campsites by either: 1) asking visitors to practice pristine site camping, selecting a site with no previous signs of use in a highly resistant/resilient setting; or 2) asking visitors to use only high-use well-established or designated campsites, with managers closing and restoring less sustainable, unnecessary, and lower-use campsites (Leung and Marion, 2004; Marion 2016).

Currently, A.T. managers and volunteers have allowed unregulated camping along most of the A.T. and have little control over the development of unnecessarily large campsites. Based on our representative sample, 28% of A.T. campsites are larger than 93 m^2, which we suggest is an ample size for any group of A.T. campers.

Even though management actions should not be inferred from our estimates of use level, our observations during fieldwork suggest that thru-hikers generally hike in small groups but prefer camping in larger groups at shelters. Many of the large campsites occur at heavily visited shelters, which provide a consistent water source and flat camping spots.

A large numbers of thru-hikers that start separately but move along the trail together, could be creating a large moving "bubble" of use that requires substantial camping capacities for only one to two months each year. Since impacts occur quickly with even low use, as the bubble moves along the trail it continually brings disproportionately high use to new areas, and is likely the driving factor responsible for campsite proliferation and expansion. Newly-created camping areas may then be found and used by other visitors, which retards or prevents recovery throughout the rest of the year (Cole and Monz, 2003; Hammitt et al., 2015; Marion and Cole, 1996).

The implication of this is that spreading out the large thru-hiking "bubble" of use is could be key to effectively reducing both the number and sizes of campsites along the entire A.T. The growing number of large annual trail town events, like Damascus Trail Days and the "hiker feeds" hosted by prior thru-hikers, also have the negative effect of reconstituting the bubble of hikers, who over time would otherwise spread out. Another implication is that "reducing" use by shifting it in time and space can effectively limit *future* increases in the areal extent of campsite impacts. Thus, encouraging thru-hikers to adopt alternative travel patterns to the traditional "north-bound" model can also be highly effective.

In contrast, seeking to reduce use levels to a point where campsites have substantially reduced size and impact is impractical and unachievable given the asymptotic use-impact relationship. The notion that by limiting use managers can solve most problems is a fallacy, as recreation ecology research and management experience have revealed that limiting use is often not a particularly effective management strategy (Hammitt et al., 2015). Research findings indicate that the effect of high-use levels is more effectively offset by management strategies that contain or concentrate use to durable impact-resistant locations.

The Influence of Other Key Variables

Regression results highlighted the strong influence of overnight site type, tree canopy cover, and sloping topography. These results provide managers with factors that are more easily manipulated to reduce the areal extent of camping impacts. To increase long-term sustainability of campsites, use should be shifted to locations that resist expansion. Regression results indicate managers can utilize aspects of the terrain to enhance a campsite's ability to resist expansion.

Campsites located in sloping terrain resist expansion and effectively concentrate use to limit campsite size, one of the most important findings of this study. The proportion of sloping terrain compared to mean or median slope in a buffer is more effective at explaining variation in area of a campsite and area of vegetation loss. This result suggests containment will be most effective if a campsite is completely surrounded by steep terrain. This finding intuitively makes sense as a campsite that is half surrounded by very steep terrain and half flat terrain could still expand substantially.

Empirical evidence of these findings are apparent in Shenandoah National Park's successful conversion to established site camping, whereby park staff shifted camping to a subset of existing campsites located in areas with low expansion potential, characterized by topographic limitations, rockiness, or dense vegetation (Reid and Marion (2004). The significance of slope in containment has been mentioned in only a few prior studies and its effect has only been empirically demonstrated in the context of side-hill campsites.

Other studies have acknowledged the environment's possible influence in constraining campsite expansion through expansion potential ratings, analysis of topographic position, and others, but none have reported the statistical significance that we obtained. We attribute our findings to the greater accuracy provided by employing GIS analyses, particularly with our use of LiDAR-generated topography data.

Consistent with previous studies, our results suggest side-hill campsites resist expansion at high levels of use and are an effective management tool for reducing areal measures of aggregate campsite impact (Daniels and Marion, 2006; Marion and Farrell, 2002; Reid and Marion, 2004). Shifting use to distinct campsites with clear topographically-defined boundaries that constrain expansion should adequately contain camping impacts and physically separate campers to enhance experiential qualities. Where there are concerns about wilderness character or naturalness, locating and developing "naturally-occurring" side-hill campsites in sloping terrain is another option. Ongoing research by the authors are investigating methods for locating naturally-occurring side-hill campsites in sloping terrain using ground-based and GIS technologies.

Moving a trail or locating new trails away from accessible and visible flat areas could reduce use to unsustainable sites or prevent creation of sites in an unsustainable area. This management technique was successfully applied in Caney Creek Wilderness by moving five kilometers of trail up a side-slope, effectively hiding a number of highly-impacted streamside campsites (Cole and Ferguson, 2009). This technique is supported by previous research indicating that backpackers typically do not travel very far off trail to camp; a survey of campsites performed by Leung et al. (2000) in Jefferson National Forest Wilderness areas found relatively few visitors practiced dispersed camping. The majority of campsites surveyed were found within sight of the trail; only 20 of 110 sites (18%) were more than 61 m away from formal trails.

Categorical measurements of offsite rugosity were significant in explaining variation in campsite size, demonstrating that a topographically rough landscape effectively deters campers and concentrates use. These results suggest the management strategy of "ice-berging" rocks, a common technique that involves burying large rocks to increase topographic roughness in potential tenting areas, could effectively deter camping. However, this practice is impractical in large flat areas as it only shifts camping to other parts of a flat area, increasing the areal extent of impact. GIS measurements of topographic roughness were not significant, possibly because the rockiness surrounding campsites exists in too fine a scale to be detected at a 1m DEM (Brubaker et al., 2013).

Figure 7. A) Grasses and sedges in meadows are highly resistant and resilient to trampling damage. This high use site still has nearly 100% of its vegetation cover, though its reduced height clearly reveals the effects of intensive trampling. B) Campsites lose trees without replacement over time, an "impact" which allows greater sunlight that supports shade-intolerant grasses, which colonize peripheral campsite areas and increase vegetation cover over time.

Positive and significant beta estimates in the area of vegetation loss regression model indicate that increases in canopy cover will increase areal measures of impact. Thus, locating campsites in open forests or along the edges of meadows where shade-intolerant grasses grow will limit areal measures of vegetation loss (Figure 7). An experimental camping study by Cole and Monz (2003) supports this finding by documenting that meadow campsites resisted trampling damage and recovered faster than identical camping activity in forested areas in the Wind River Mountains of Wyoming. Similarly, Eagleston and Marion (2017) reported that tree loss over 32 years on BWCAW campsites resulted in increased sunlight and significant increases in the percent and areal extent of vegetation cover, primarily trampling-resistant grasses, which significantly reduced measures of exposed soil (depicted in Figure 7B). Open grassy campsites in forests are ecologically and aesthetically different than the original landscape, "unnatural" changes that could possibly reduce a visitor's perception of wilderness and wilderness character (Eagleston and Marion, 2017; Eagleston and Marion, 2018). Shifting camping to more open forests and meadows could alleviate these concerns and reduce the hazards of visitors camping near dying or dead trees.

Ecoregion explained a significant amount of variation across dependent variables, however, managers do not have the option to shift recreational use on the scale of ecoregions. Variations in campsite size may be due to the amount of bedrock outcrops, thinner soils, or denser vegetation types in a particular region.

As mentioned previously, other management strategies have been successful in concentrating use towards the center of campsites. This study was not able to evaluate the effect of several practices because they did not appear or there were not enough occurrences within the random sample. An adapted table (Table 4) from Marion and Farrell (2002) summarizes the actions found in this and other studies.

While this study formed a clearer definition of an ecologically sustainable campsite, successfully shifting use away from sensitive areas preferred by visitors may require other management actions. For example, two studies indicate that proximity to water to be an important feature of a campsite to visitors (Farrell et al., 2001; Lime, 1971). Locating or constructing sustainable campsites should also consider features or characteristics that attract use or enhance desirability. Success at Isle Royale National Park was partially attributed to managers actively maintaining smooth, welldrained tenting pads and providing visually obvious site boundary cues that encourage visitors to stay on-site (Farrell and Marion, 2002). In an effort to understand camping compliance, researchers in Shenandoah National Park conducted interviews with visitors to inquire about their knowledge of camping policies and site selection (Reid and Marion, 2004). The most commonly cited methods for identifying campsites were bare ground (34%), flat ground (18%), fire rings (16%), and good tent sites (14%). Knowing this, managers can effectively draw campers to sustainable campsites and erase visual cues that attract them to unwanted campsites.

Table 4. Management actions to reduce camping impacts, adapted from Marion and Farrell (2002).

Action	**Impact Reduction Effect**
Established or designated site camping	Implements a containment strategy to concentrate impact on a limited number of resistant sites
Dispersed pristine site camping	Reduces camping use to levels that prevent lasting impact.
Limit on site numbers to achieve high site occupancy rates	Reduces site numbers and area of camping disturbance to the minimum necessary
Group size limits	Minimizes site sizes by limiting tent numbers
Placement of campsites in sloping terrain, including naturally occurring or constructed "side-hill" campsites	Enlists topography in promoting activity concentration to intended use areas
Placement of campsites in areas with substantial offsite rockiness	Improves activity concentration within site borders
Location of campsites in open forests or meadows	Places campsites on resistant and resilient grasses and sedges
Placement of trails away from undesired camping locations (e.g. large flat areas near water)	Reduces likelihood of campsites forming in undesirable locations
Construction and maintenance of improved tenting sites	Improves activity concentration by attracting visitors to the intended use areas
Facilities (e.g., shelters, anchored picnic tables)	Attracts and concentrates use
Site maintenance that ruins offsite areas that receive use	Improves activity concentration and discourages site expansion
Educational messages that encourage use of core areas	Improves activity concentration
Clustering of campsites with a minimum specified inter-site distance	Limits wildlife habitat fragmentation while enhancing experiential conditions
Campsite borders of rocks or logs	More clearly defines intended campsite borders
Anchored fire rings or placement of large flat "kitchen" rocks for stove use	Attracts and concentrates cooking activity at a single site location
Provision of food storage boxes or cables	Enhances safe food, trash, and smellable storage; protects trees from rope damage

Success may also require efforts to close and rehabilitate old campsites. Success in closing a number of campsites over the course of 32 years in the Lee Metcalf Wilderness, MT was attributed to persistent maintenance efforts to eliminate visual evidence of campsites and improving conditions on legal campsites (Cole, 2013). In another study, persistent restoration and rehabilitation efforts were key to effectively reducing the areal extent of campsite impacts and a successful established site camping policy (Reid and Marion, 2004).

Management actions should also address impacts that are driven by visitor behavior, such as improperly disposed human waste, cutting of trees, and trash. Sites that are heavily impacted due to visitor behavior will require different actions to limit such behaviors (Monz and Twardock, 2010).

A holistic view of campsite sustainability considers social and managerial aspects that this study has not addressed. Aspects of social sustainability could include potential for user conflicts, potential for safety-related incidences, the quality of visitors' experiences, and the ease of interpreting management policies. Aspects of managerial sustainability could include considerations of monetary or maintenance needs, such as removal of hazard trees.

As mentioned in Newman et al. (2006), campsite monitoring protocols remain virtually unchanged since conception by Cole (1981) and modification by Marion (1991). The most precise methods, as evaluated by Marion (1991) through field trials, are also the most time consuming. Monitoring programs choice of campsite size collection method often requires a trade-off between assessment time, precision and accuracy; good campsite size data is often limited by the multitude of ephemeral seasonal personnel and volunteers collecting the data (Newman et al., 2006). The GPS method of campsite size measurements could increase efficiency and decrease user error of monitoring data. Spatially referenced campsite polygons orient and place campsite shapes within the landscape allowing for more accurate modeling in GIS. Paired with high-resolution DEMs, longitudinal data of this kind will allow managers and researchers to the ability to see the influence of topography on the growth and formation of campsites in relation to the landscape over time. Similar to published trail research, armed with information about what topographic variables influence the sustainability of campsites we can identify naturally sustainable areas to move camping.

Further research is needed to compare accuracy, precision, and efficiency of GPS methods for campsite size to other measurement methods, and to assess the amount of error in different vegetation types and topographic configurations. We suggest that future researchers should not collect areas of small polygons, ≤ 3.5 x 3.5 m, using the GPS method and should instead estimate smaller areas using the GFM.

This is the first study that has conducted comprehensive regression modeling of large numbers of factors to assess and document their relative influence. It also incorporated extensive GIS analyses and utilized accurate LiDAR-derived topographic data to characterize the influence that topographic characteristics have on campsite impact. Future work should continue to refine, expand and calibrate these methods; seeking the optimal scale(s) for GIS-derived variables which may more accurately characterize their influence on campsite size. For example, LiDAR DEMs at 1m resolution may be characterizing large slope values due to small changes in the terrain that may or may not influence camping decisions. Terrain roughness and topographic position indicators were developed in literature using lower resolution DEMs and the published classification break points may not be calibrated for the spatial scale of a 1m DEM. Work should be done to calibrate these indices for working with data at this smaller spatial scale. Additionally, errors associated with either campsite location accuracy, campsite polygon accuracy or in the LiDAR data itself likely can have significant influence on the viability of these analyses.

CHAPTER 7: CONCLUSION

A cardinal rule of camping management is managers should only shift use from less- to more-sustainable locations and only when they are confident that closure and recovery work will be successful at the original location (Cole, 2013; Cole et al., 1987). Restoration studies reveal that even low levels of camping use are sufficient to prevent recovery, so shifting use without recovery merely increases the aggregate area of camping impact (Cole et al., 2012). Advancing our knowledge of campsite sustainability is critical to enhancing managers' abilities to effectively evaluate and rate existing or potential new sites for sustainability, and to shift use from less to more sustainable campsites.

This study increases our understanding of environmental characteristics influences on the areal extent of camping impact along a large representative sample of AT campsites. The relative influence of significant variables provides managers with the knowledge needed to improve selection, design, and management of campsites for sustainability. These results support indirect management methods that rely on the design and location of campsites in places that naturally resist proliferation and expansion impacts rather than actions that regulate actions which restrict visitor freedom. In response to rising visitation, the strategies and practices presented can aid in identifying and creating ecologically sustainable campsites. Proactive and focused camping management actions that manipulate influential factors are key to limiting visitor impacts and maintaining a sustainable inventory of campsites over time. However, while this research more fully describes the necessary elements required for sustainable camping management, we note that more research is needed to identify effective options for successfully shifting use to sustainable campsites.

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APPENDIX A

LiDAR Data Specifications

Table 5. LiDAR data specifications. NVA = Non-vegetated Vertical Accuracy; VVA = Vegetated Vertical Accuracy; FVA = Fundamental Vertical Accuracy; CVA = Consolodated 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 0.170m VVA	Connecticut Statewide LiDAR 2016, Capitol Region Council of Governments
GA	Fannin, Habersham, Union	2010	Photo Science Inc.	unspecified	1.5	3m	≤0.15m	USGS LiDAR Point Cloud
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	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	0.76m	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 C

Recreation Site Assessment Manual
Appalachian National Scenic Trail

(*version 4/29/2016*)[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, 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 sampled 4-mile 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. <u>in tenths</u>) as backup
- ☐ This manual on waterproof paper with field forms (forms/photos from previous survey)
- ☐ Digital camera w/GPS, w/charged & spare batteries, computer/cords for downloading/charging
- ☐ Clipboard, monitoring manual, blank field forms (some on waterproof paper), small notebook, calculator, pens

1 - Developed by Dr. Jeff Marion, USGS Patuxent Wildlife Research Center, Field Station at Virginia Tech/ Department 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, some of which are in color, 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. USDI, National Park Service, Natural Resources Report NPS/NRVT/NRR-91/06, pages 46-51.

General Site Information

1) **Site Number**: Each site must have a unique number. Examine mapped site locations, data forms, and photos to determine if each site was present during the previous survey. If the site has been previously surveyed then record the old number (if positively known). If the site has not been previously surveyed then assign a new number and record it.

   Note – Guidance for odd/rare situations: 1) A satellite use area has become the main site and the previous site is now a satellite site or has recovered. Use the same site number from the earlier survey. Describe the situation in the comments section. 2) Two former sites have merged. Apply one of the former site numbers to the entire site, noting the merge and other site number in the comments. 3) The site was rehabilitated by staff or has recovered on its own such that there is no current visual evidence of trampling sufficient to create site boundaries. If possible retake a photo from previous survey photo point but do not measure the site.

2) **Site Type**: Record the most specific applicable code: **N** - new site; **L** - current site, also present in last survey; **S** - current site, satellite in last survey; **SR** - site is recovered.

3) **Inventoried by**: Identify the initials of field personnel assessing the site.

4) **GPS**: GPS coordinates for site, WGS84 datum.

5) **Date**: Month, day, and year the site was evaluated (e.g. July 1, 2015 = 07/01/15).

   Site remeasurement - Due to phenological and site use changes which occur over the use season, it is critical that sites be re-measured as close to the initial assessment month and day as possible, preferably within 1 to 2 weeks if early in the use season, 3 weeks if later.

6) **Location**: Record an area name (e.g., Bigelow Preserve, W. Peak).

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

7) **<u>Site Expansion Potential</u>**: 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.

8) **<u>Tree Canopy Cover</u>**: 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) **<u>Rock Substrate</u>**: 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) **<u>Use Type</u>**: Record the predominant use: Campsite = C, Vista = V, Trail junction or rest/waiting spot = R, Unknown (combination) = U. Based on observations during field work and/or trail club members.

11) **<u>Use Level</u>**: Low = L, Moderate = M, Heavy = H Obtain from local club members or agency staff when possible.

Impact Indicators

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 2.1). Project site boundaries straight across areas where trails enter the site.

Include any adjacent associated ***"satellite"*** tenting spots or use sites. Use your judgment to separate out and exclude nearby campsites or day-use sites – measure these separately. Sometimes (rarely) there can be an essentially ***"undisturbed island"*** of vegetation within a camp or recreation site boundary. If present, measure the dimensions of these islands – 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 <u>exclude</u> some of the disturbed area along each side in order to balance out some of the undisturbed area <u>included</u> 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 x. Take your time and be very careful in making your calculations.

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

13) **<u>Condition Class</u>**: 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.

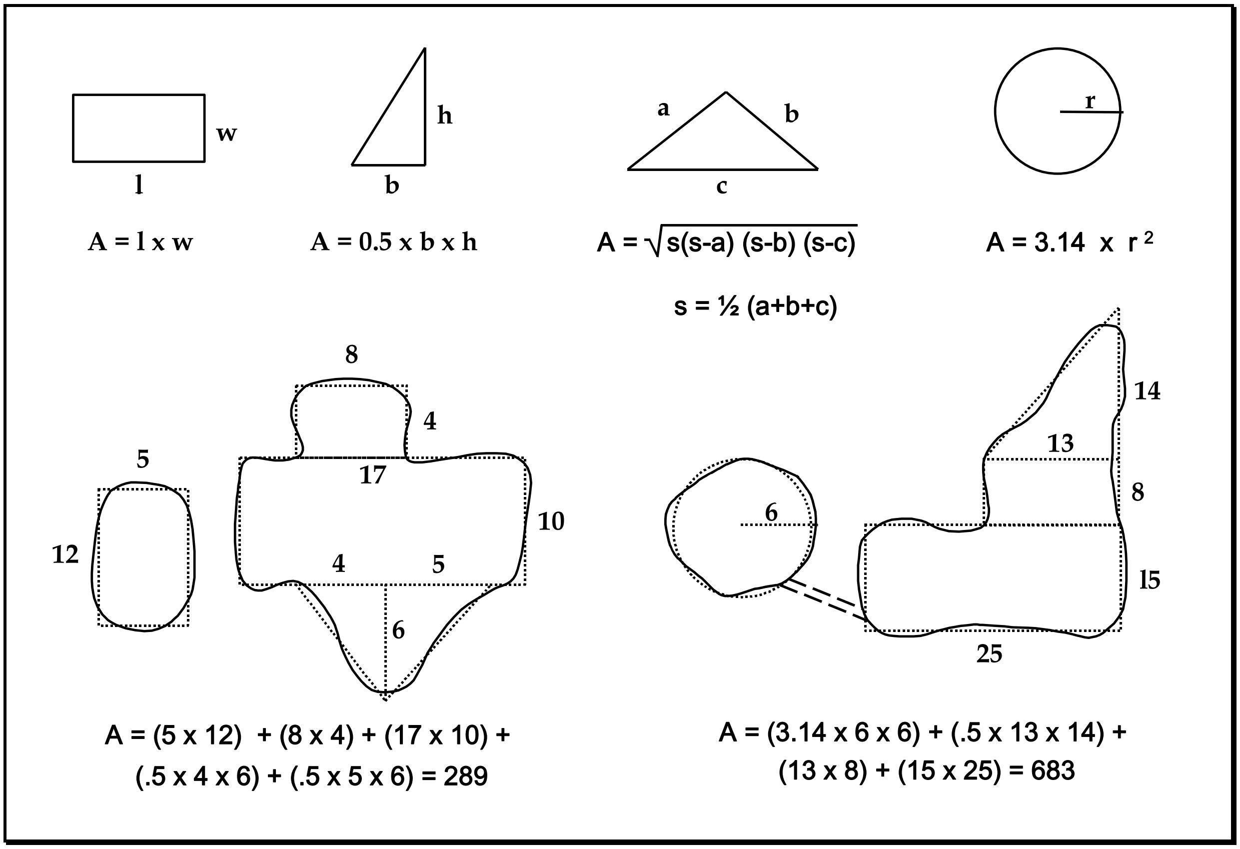

Figure 2.1. The Geometric Figure Method for determining the size of campsites and recreation sites.

14) **<u>Vegetation Ground Cover On-Site</u>**: 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. <u>Include any disturbed "satellite" use areas and exclude undisturbed "islands" of vegetation.</u> 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**

15) **<u>Vegetation Ground Cover Off-Site</u>**: 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. <u>The intent is to locate an area which would closely resemble the site area had the site never been used.</u> 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.

16) **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 above.

17-19) **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).

20-22) **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

23) **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.

24) **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.

25) **Site Photograph**: If the site has not been previously surveyed, 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. Delete and retake the photo if the lighting is bad or it's out of focus.

If the site has been previously surveyed position yourself to replicate the earlier site photo. Frame your photo and adjust the zoom lens if necessary to include the same area depicted in the earlier photo. If the site has expanded to areas that are not visible in the viewfinder then turn the camera to capture these areas or move back if necessary. ***Enter the photo number.***

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

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)

A.T. Campsite and Recreation Site Assessment Monitoring Form

ver. 1/9/15

General Site Information

1) Site No. ________ 2) Site Type _____ 3) Inventoried by: ______________________

4) GPS: ____________________________ 5) Date _ _ / _ _ /

6) Location: ____

Comments: ____

____

____

Inventory Indicators

7) Site Expansion Potential: P M G _____

8) Tree Canopy Cover: (%, use item 14 midpoint categories below) _

9) Rock Substrate: (%, use item 14 midpoint categories below) _____

10) Use Type: Campsite = C, Vista = V, Trail junction or rest/waiting spot = R, Unknown (combination) = U _____

11) Use Level: Low = L, Moderate = M, Heavy = H _____

Impact Indicators

12) Total Site Area: ______ft²

13) Condition Class (R, 1 to 5) _____

14) Vegetation Ground Cover On-Site (Use categories below) _____

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

15) Vegetation Ground Cover Off-Site (Use categories above) _____

16) Exposed Soil (Use categories above) _____

17-19) Tree Damage None/Slight ___________________ Moderate ________________________Severe _________

20-22) Root Exposure None/Slight ___________________ Moderate ________________________ Severe _________

23) Tree Stumps (#)_____________________ _____

24) Access Trails (#) _____

25) Photo Number _______