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LONG-TERM MONITORING METHODS FOR ASSESSING VISITOR IMPACTS TO MOUNTAIN SUMMITS

Final Report, September 2013

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EXECUTIVE SUMMARY

This study investigated methods for assessing and monitoring off-trail visitor impacts on Acadia National Park's Cadillac Mountain summit. The park's subalpine summits receive high visitation due to their spectacular vistas of park and coastal scenery. Due to repeated glacial scouring, these summits have extensive bedrock exposure interspersed with relatively thin lenses of soil and vegetation. These settings readily permit off-trail hiking, but visitors repeatedly encounter and must cross the patches of soil and vegetation. Decades of off-trail traffic have removed the vegetation cover from a large but disconnected network of informal (visitor-created) trails. There are also some larger nodal areas of trampling disturbance and numerous areas of more dispersed trampling impact.

The off-trail hiking and associated resource impacts have long been a concern of park managers, and they have implemented measures to reduce impacts, including the provision of formal trails, trail management actions (construction of steps, tread hardening, and trail borders), and Leave No Trace educational messaging. However, the trampling damage to subalpine soils and vegetation has persisted and the National Park Service funded this study to develop assessment and monitoring protocols to measure and track off-trail resource impacts. These protocols can be employed to monitor resource conditions over time and evaluate the efficacy of measures applied to reduce impacts or restore natural conditions.

Study objectives focused on three tasks:
1) collect baseline data on recreation-related impacts to vegetation and soils on mountain summits,
2) identify potential indicators of change and develop efficient protocols for quantifying vegetation and soil impacts, and
3) test, refine, and apply protocols to demonstrate their utility.

We focused our research efforts on measurement-based assessment protocols that could be replicated with acceptable measurement error to provide data that accurately document changes in resource conditions over time. Based on our reviews of the literature and through discussions with park staff and the research team we decided to develop protocols to document visitation-related impacts through three separate but related impact assessment protocols. These included: 1) an assessment of visitor-created informal trails, 2) assessments of soil loss, and 3) assessments of land cover (vegetation/groundcover) changes. The protocols developed and applied for each

of these are fully described in the Appendices of this report and all associated data and photographs were included on a CD provided to park staff.

Informal Trails. A study area was defined on the summit of Cadillac Mountain that included 17.5 acres. Within the study area, field staff conducted a comprehensive GPS survey of informal (visitor-created) trails. A total of 323 informal trail segments were mapped, totaling 1.46 miles, about three times longer than the total length of formal trails within the study area (see Figure 13). These trails are uniformly distributed throughout the Cadillac summit area and coincide with patches of vegetation, which they bisect to link areas of exposed rock. Informal trails have a mean width of 25 inches and 76% of them were classified as Condition Class 3-5, with vegetation cover mostly lost and soil exposed and or eroding. An estimated 17,188 ft^2 of direct trampling disturbance to summit area vegetation and soils are associated with these informal trails. NPS signs posted throughout the summit area ask visitors to "Step on the paved trail or rocks" (see Figure 1), thus off-trail hiking is permitted.

Soil Loss. Even the casual observer can see evidence that substantial amounts of soil have been lost in many locations around the Cadillac Mountain summit. Protocols were developed to improve the precision and accuracy of traditional methods for documenting the loss or deposition of soil by employing small portable lasers that allow accurate measurements of soil profiles (see Figure 9). These protocols rely on the establishment of permanent transects relocated by GPS data, photographs, and small 3/16th inch holes drilled into the bedrock at the ends of each transect. This allows a small laser to be set up to project a line over the holes at a known elevation, and highly accurate measurements from the laser line to the ground surface along each transect. These data allow computation of a cross sectional area under the line, providing a baseline for comparison with future datasets to detect soil deposition or loss. Eight transects (four within the wooden summit exclosures) were assessed as part of our exercises and park staff can establish additional transects as needed in the future. Detailed protocols for setting up transects, taking measurements, and making all calculations are provided in this report.

Land Cover. A number of methods and options were developed applied, evaluated, and refined in our efforts to provide an efficient, accurate, and precise method for documenting trampling damage to vegetation and soils across large areas of mountain summits. This was the most challenging research component, primarily related to the difficulties of capturing a representative sample and documenting dispersed trampling impacts. Photographic methods for capturing and documenting vegetation and soil conditions were carefully evaluated in lieu of direct field assessments due to their high degree of efficiency in data collection and limited disturbance of visitor enjoyment of the high use Cadillac summit. We investigated and abandoned aerial photography and satellite imagery due to their poor resolution and inability to detect visitor trampling damage to vegetation and soils. Instead, we settled on ground-based high-resolution digital photography.

A research design based on a statistical power analysis was conducted to determine the sample size needed based on the size of the study area. A grid overlay was developed using ArcGIS to produce and locate a random stratified sample of 317 sample points (see Figure 11). Field staff navigated to the coordinates of each sample point using a Trimble GPS unit, where a metal quadrat was placed with a vertical boom allowing for camera attachment and taking standardized quadrat photographs.

The cover of different classes of vegetation, bedrock, lichens, exposed soil and other attributes were assessed using several relatively efficient methods. These included 1) onscreen estimates of visually obvious trampling disturbance to vegetation, soil, and rock, 2) application of a SamplePoint computer software program that directs staff to make groundcover estimates at 100 sampled points on each photograph, 3) onscreen assessments by project staff using a standardized grid overlay to enhance estimate accuracy, and 4) application of VegMeasure and ENVI computer software that provide advanced spectral image processing to produce estimates of land cover classes. Protocols for applying each method are included in the Appendices of this report.

While each of these methods provided reliable data, only the first method was able to specifically isolate and provide quantifiable measures of trampling-related disturbance to vegetation and soils. We identify two indicators, visually trampled vegetation cover and exposed soil, as preferred indicators for monitoring off-trail impacts on Acadia's summits. Periodic assessments of these indicators can be obtained by taking and analyzing new sets of photos from the summit sample points, or by returning to each point to assess these indicators directly.

These procedures yielded accurate estimates of off-trail trampling disturbance to the Cadillac Mountain summit. The informal trail system accounts for 2.2% of the summit study area (note that these trails were only assessed within the vegetation patches). Method 1 onscreen estimates of visually obvious trampling disturbance (also conducted within vegetated areas) was 1.8%, and of exposed soils was 6.0%. Subtracting the informal trail system disturbance estimate (2.2%) from the combined Method 1 estimate (7.8%) indicates that 5.6% of the trampling disturbance occurs within vegetated patches away from the informal trails. This percentage was unexpectedly high and indicates that a considerable amount of dispersed traffic is occurring, with associated visually obvious impacts to vegetation and soils.

INTRODUCTION

The National Park Service accommodates nearly 300 million visitors per year, visitation that presents managers with substantial challenges. The increasing number of visitors inevitably contributes negative effects to fragile natural and cultural resources and to crowding and conflicts that degrade the quality of visitor experiences. "Providing opportunities for public enjoyment is an important part of the Service's mission; but recreational activities and other uses may be allowed in parks only to the extent they can take place without causing impairment or derogation of a park's resources, values, or purposes" (NPS, 2001). This statement, from the National Park Service (NPS) *Management Policies*, provides a strong mandate to guide recreation management decisions in protecting park resources and values. This policy guidance recognizes the legitimacy of providing opportunities for public enjoyment of parks. However, the *Management Policies* also acknowledge that some resource degradation is an inevitable consequence of visitation and direct managers to "ensure that any adverse impacts are the minimum necessary, unavoidable, cannot be further mitigated, and do not constitute impairment or derogation of park resources and values" (NPS, 2001).

Acadia National Park is relatively small in size (35,000 acres) compared to other national parks, yet it ranks among the highest for visitation (2-2.7 million visits/yr), making it is one of the most intensively visited National Parks (NPS 2011). Visitation density is particularly high at popular attraction features, which if not carefully managed can contribute unacceptable impacts to natural and cultural resources. One such popular attraction destination at Acadia NP is the summit of Cadillac Mountain, which is easily accessed by a paved park road and three popular hiking trails. A 2008 survey found that 75% of park visitors visit the summit of Cadillac Mountain (Park Studies Unit 2009) but a survey conducted in 2001 suggested that about 500,000 people annually visit the top by road or trails (Jacobi 2001). At 1,532 ft, Cadillac Mountain is the highest peak along the eastern U.S. coastline and commands spectacular vistas of the Maine coastline along an easy 1/3 mile hike on a paved loop trail. Park policies have encouraged visitors to remain on the paved trail but do allow visitors the option of walking off-trail on bedrock surfaces (Figure 1), which are common, but interspersed with vegetated areas (Figure 2).

An experimental study designed to evaluate options for deterring off-trail hiking at the summit found that 74% of summit visitors venture off the paved summit trail in the absence of educational signs and barriers (370,000 off-trail hikers/yr) (Park *et al.* 2008). The most effective educational sign treatment reduced off-trail hiking to 24.3% of visitors (121,500 off-trail hikers/yr), and educational signs and low fencing reduced off-trail hiking to 1.2% (6,000 off-trail hikers/yr). Given these estimates, it is clear that off-trail hiking is common on the summit of Cadillac Mountain and will continue to challenge park managers in preserving the summit's thin mantle of vegetation and soils.

Figure 1. Past and current park policy allows visitors to hike off-trail on adjacent areas of bedrock.

Figure 2. Note the paved trail, educational sign (center), and President Obama's daughter exploring a trailside bedrock area. (White House photo by Pete Souza).

Similar problems with trampling impacts to fragile mountaintop vegetation and soils occur throughout the rest of Acadia NP in the backcountry. Acadia's summits provide outstanding vistas that have long been high-use attraction features, drawing large numbers of day-hikers. These summits generally lack the dense woody vegetation that restricts off-trail hiking and impacts at lower elevations. When visitors leave the tree line, areas of bedrock often attract or facilitate off-trail hiking and exploration. However, visitors must inevitably traverse vegetation patches within and between exposed areas of bedrock and when they do vegetation and soil loss occur.

Management actions have included both indirect actions, such as Leave No Trace educational messaging (Figure 1), and direct actions, such as restrictive fencing and exclosures (Figure 3). Due to the lack of a monitoring program, the efficacy of these actions cannot be evaluated, but direct observations and data in this report reveal that substantial trampling disturbance is occurring to off-trail vegetation and soils on the Cadillac Summit. The NPS funded research to investigate the efficacy of alternative educational sign messaging and site management actions designed to deter off-trail hiking on Cadillac Mountain, published as Park and others (2008). A similar study was funded and conducted in a backcountry setting on Gorham Mountain in Acadia NP (Park *et al.* In Press). The NPS also funded this research study to develop assessment protocols to document and monitor recreation-related vegetation and soil impacts, and enable managers to evaluate the efficacy of corrective or restorative actions.

Study Objectives

Study objectives focus on three tasks:

1) collect baseline data on recreation trampling-related impacts to vegetation and soils on mountain summits,
2) identify potential indicators of change and develop efficient protocols for quantifying vegetation and soil impacts, and
3) test, refine, and apply protocols to demonstrate their utility.

Research was also guided by the potential need to incorporate study results into carrying capacity planning and management decision-making frameworks, which require quantitative evaluations of indicators and standards of quality (NPS 1997). Due to its high visitation and management significance, the Cadillac Summit served as the study area for this research, though study results should be applicable to other mountain summits within or outside of Acadia NP.

Figure 3. These wooden barricades with signs asking visitors to not enter the exclosures have been placed at several locations on the Cadillac Summit to protect patches of fragile sub-alpine vegetation and soil. Note the substantial prior loss of soil and vegetation in the foreground, as revealed by the lack of green and gray lichen on the pink granite bedrock.

Monitoring Program Capabilities

Visitor impact monitoring programs can be of significant value when providing managers with reliable information necessary for establishing and evaluating resource protection policies, strategies, and actions. When implemented properly and with periodic reassessments, these programs produce a database with significant benefits to protected area managers (Figure 4). Data from the first application of impact assessment methods developed for a long-term monitoring program can objectively document the types and extent of recreation-related resource impacts. Such work also provides information needed to select appropriate biophysical indicators and formulate realistic standards, as required in VERP or LAC planning and decision making frameworks (NPS 1997).

Reapplication of impact assessment protocols as part of a monitoring program provides an essential mechanism for periodically evaluating resource conditions in relation to standards. Visitor impact monitoring programs provide an objective record of impacts, even though individual managers come and go. A monitoring program can identify and evaluate trends when data are compared between present and past resource assessments. It may detect deteriorating conditions before severe or irreversible changes occur, allowing time to implement corrective actions. Analysis of monitoring data can reveal insights into relationships with causal or non-causal yet influential factors. Following the implementation of corrective actions, monitoring programs can also evaluate their efficacy in achieving management objectives.

- Identify and quantify site-specific resource impacts.
- Summarize impacts by environmental or use-related factors to evaluate relationships.
- Aid in setting and monitoring resource conditions standards of quality.
- Evaluate deterioration to suggest potential causes and effective management actions.
- Evaluate the effectiveness of resource protection measures.
- Identify and assign priorities to maintenance needs.

Figure 4. Capabilities of visitor impact monitoring programs.

LITERATURE REVIEW

In recreation ecology, the term *impact* is commonly used to denote any undesirable visitor-related change in these resources. In this study, the impacts of off-trail walking and associated trampling to sub-alpine vegetation and soils are the subject of interest. While a number of studies have examined the impacts of recreational trampling on high-elevation vegetation (Cole & Monz 2002, Willard *et al.* 2007, Ebersole *et al*. 2002, Pickering & Buckley 2003), none have focused on the development of monitoring protocols.

Three primary issues associated with the development of a visitor impact monitoring program are the spatial pattern and severity of visitor impact, the selection of indicators that will be monitored, and their assessment procedures (Marion & Leung 2011). When visitor traffic is sufficiently concentrated to create informal trails these can be located to assess their lineal extent and condition. Permanent transects arrayed across heavily trafficked spots can also be established to provide accurate measurements of vegetation cover and soil loss. However, these options do not capture or reflect impacts created by low levels of dispersed traffic. To address this deficiency we included a monitoring option that efficiently samples the entire study area to document changes in various categories of ground cover, and of visually obvious trampling disturbance to vegetation, soils and rock. This work establishes a baseline of resource conditions and comparisons of these data over time allow evaluations of long-term trends, though these may be related to changes in recreational traffic and/or other factors (e.g., climate change). However, comparison of changes in areas that exhibit the impacts of recreational traffic with areas that appear unaffected by traffic can aid in isolating the influence of non-recreational factors.

Impacts from Dispersed and Concentrated Traffic

Off-trail walking can produce an array of direct and indirect effects to vegetation and soils (Table 1). Even light traffic can alter the appearance and composition of vegetation by reducing vegetation height and favoring trampling resistant species. Off-trail walking can also damage and/or remove trampling-susceptible vegetation such as broad-leafed herbs, and pulverize or remove organic litter (Cole 2004, Leung & Marion 1996). Higher intensities of trampling can directly remove some or all vegetation cover and alter soils – causing informal (visitor-created) trails or recreation sites to develop (Hammitt & Cole 1998). Loss of tree and shrub cover can increase sunlight exposure, promoting further changes in composition by favoring sun-loving plants that are more resistant and resilient to trampling (Hammitt & Cole 1998, Leung & Marion 2000). Off-trail walkers can also introduce and disperse non-native plant species, some of which may out-compete undisturbed native vegetation and migrate away from trails (Cole 1987, Pickering & Mount 2010). Direct trampling or the effects of these indirect impacts can also contribute to the reduction or loss of rare plants.

Generally, only moderate to high levels of trampling lead to visible and quantifiable impacts to soils, including soil compaction, muddiness, and erosion (Hammitt & Cole 1998, Leung & Marion 1996, Tyser & Worley 1992). Soil compaction decreases soil pore space and water infiltration, which can increase muddiness, water runoff and soil erosion. The erosion of soils along trails exposes rocks and plant roots, creating a rutted, uneven tread surface. Eroded soils may smother vegetation or find their way into water bodies, increasing water turbidity and sedimentation impacts to aquatic organisms (Fritz 1993). Visitors seeking to circumvent muddy or badly eroded sections contribute to tread widening and creation of parallel secondary treads, which expand vegetation loss and the aggregate area of trampling disturbance (Marion 1994, Liddle & Greig-Smith 1975).

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

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

Formal developed trail systems rarely access all the locations that visitors want to go so the establishment of informal visitor-created trails is commonplace in heavily visited areas. Sometimes referred to as *social* trails, their proliferation in number and expansion in length over time are perennial management concerns. Furthermore, because informal trails are not professionally designed, constructed, or maintained, they can contribute substantially greater resource impacts than formal trails. Many of these impacts are related to their poor design, including alignments parallel to slopes, multiple trails accessing the same destination, routing through fragile vegetation, substrates, or sensitive wildlife habitats, and disturbance of rare flora, fauna, or archaeological sites. These design attributes also make informal trails far more susceptible to tread impacts, including expansion in width, soil erosion, and muddiness.

Once created, managers have found it difficult to deter informal trail use and even when successful, their recovery requires long periods of time (Grabherr 1982, Cole 1990, Boucher *et al.* 1991, Roovers *et al.* 2005). Restoration work can hasten recovery but is expensive and may require archeological assessment and compliance work. Informal trails are particularly problematic because they become more visually obvious as they form, acting as a “releasor cue” that draws even more visitors off formal trails (Roggenbuck 1992, Brooks 2003). Further, informal trails are often indistinguishable from formal trails, except for the lack of formal trail blazes or markings.

Previous research has investigated the deterrence of off-trail hiking through educational messages (Johnson & Swearingen 1992, Hockett *et al.* 2010) and site management (Matheny 1979, Hockett *et al*. 2010, Johnson *et al.* 1987, Sutter *et al.* 1993, Park *et al.* 2008). Informal trail proliferation and resource impact is a problem across all types of protected natural areas as shown by research and monitoring studies conducted around the globe (Grabherr 1982, Cole 1990, Ferris *et al.* 1993, Marion & Cahill 2006, Manning *et al.* 2006, Marion & Hockett 2008a, Wimpey & Marion 2011a, 2011b, Wood *et al.* 2006). Until recently, few studies have extensively mapped or investigated the resource impacts of informal trail networks within protected natural areas (Cole *et al.* 1997, Leung *et al.* 2002, 2011, Marion & Hockett 2008b, Leung & Louie 2008, Wimpey & Marion 2011a). However, several investigators have collected informal trail counts in conjunction with campsite, recreation site, or formal trail inventories (Marion 1994, Leung & Marion 1999b, Dixon *et al.* 2004, Marion & Cahill 2006, Wimpey & Marion 2011b, Wood *et al.* 2006).

Monitoring Impacts from Concentrated Off-trail Traffic

A variety of efficient methods for evaluating trails and their resource conditions have been developed and described in the literature, as reviewed and compared by Cole (1983), Leung and Marion (2000), Marion & Leung 2001, and Marion *et al*. (2012). Multiple trail survey protocols can also be integrated in a combined survey (Bayfield & Lloyd 1973, Olive & Marion 2009).

A comprehensive review of the literature found very few reported examples of research or monitoring efforts focused on assessing informal trail networks (Marion *et al.* 2006). While informal trails likely occur in nearly every protected area, managers have frequently ignored their presence, limiting monitoring efforts to formal trail systems. Furthermore, conventional trail condition assessment protocols can be difficult to apply to informal trails due to their unique spatial characteristics (Marion & Leung 2001). Informal trail segments are often comparatively numerous, short, and braided in complex patterns, creating sampling and assessment difficulties (Leung & Marion 1999a).

However, scientists and managers have recently been focusing greater attention to the impacts of informal trail networks and to developing methods for assessing and monitoring their resource impacts. Managers seeking to assess informal trails must consider two categories of attributes: spatial and resource condition. Spatial attributes include the location, arrangement, and lineal extent of informal trails. Resource condition attributes include the impacts to vegetation, organic litter, and soils along informal trails.

It is possible to assess most spatial attributes using scale-appropriate airborne remote sensing techniques if trails are not under concealing vegetation or when they are readily visible in leaf-off photography (Witztum & Stow 2004). Kaiser and others (2004) applied the best available techniques, including high spatial resolution (0.6m/pixel) digital multi-spectral imagery, digital image processing, and visual image analysis techniques, to detect and delineate new illegal immigrant trails in shrub lands along the US-Mexico border. They found that an automated linear feature extraction routine (Feature Analyst in ArcView GIS), followed by manual interpretation, delineation, and editing using false color infrared imagery, yielded the most accurate results. However, this method only resulted in 56% of ground-based Global Positioning System (GPS) trail locations matching by length, in part due to shielding overhead vegetation.

Extending this work, Cao and others (2007) evaluated three trail monitoring approaches and two types of spectral transformation to aid in locating trails in imagery, procedures designed to evaluate temporal changes in US-Mexico cross-border trail networks. They found that a map-to-image differencing approach was the most sensitive and reliable in detecting new trails, though no ground-based GPS surveys were conducted for comparison. For disturbed areas where the trail networks were extensive, Principal Component Analysis (PCA) of the image was more effective at enhancing new trails. For densely vegetated areas, a Normalized Difference Vegetation Index (NDVI) image yielded more interpreted trails. The authors stress that high quality, well registered, and radiometrically matched multi-temporal image datasets are needed for efficient and reliable trail map updating procedures. Imagery from different years must also be collected at the same phenological time and time of day to minimize errors due to vegetation seasonality and sun angles.

We conclude that these techniques are currently impractical for most protected area managers due to the substantial expense associated with image acquisition, technician expertise and time, and substantial inaccuracies associated with concealing vegetation cover and the methodologies used. Such methods are also problematic when informal trails are faint and/or discontinuous. We expect, though, that improvements in analysis methods, along with reductions in cost of remotely sensed data could improve these options in the next 5-10 years. Currently, airborne lidar is showing the most promise as a remote sensing tool. Archaeologists are using lidar to find thousand year old ruins under concealing vegetation (Chase *et al.* 2012).

Point-based assessment methods are the most efficient, and include trailhead and transect surveys. A highly efficient method is to inventory informal trail junctions with protected area roads, trails, or recreation sites, documenting junction locations with a recreation or professional grade GPS, odometer, or measuring wheel (Bacon *et al.* 2006, Marion & Cahill 2006).

Alternately, an approach developed for Zion National Park applied transects at fixed intervals within travel zones to document the number and location of intersecting informal trails (Marion & Hockett 2008a). Both of these methods were also applied in Denali NP in a study designed to develop an array of efficient informal trail monitoring protocols (Marion & Wimpey 2011).

Line feature methods provide more comprehensive information on the spatial distribution and lineal extent of informal trail networks (Wimpey & Marion 2011a, Marion *et al.* 2012). This method requires a GPS set to collect line features (tracks) as field staff walk all informal trails within a management unit (Wimpey & Marion 2011a). GPS surveys can employ recreational grade units (about 2-5m accuracy with real-time data correction units) but commercial grade units (<2m accuracy with post-processing) provide more accurate data. Trail information from the GPS is input to a Geographic Information System (GIS) for display and analysis of trail attributes (Wolper *et al.* 1994, Wing & Shelby 1999, Marion *et al.* 2012). This commonly applied protocol has been reported in several publications (Bacon *et al.* 2006, Cole *et al.* 1997, Leung *et al.* 2002, 2011, Leung & Louie 2008, Manning *et al.* 2006, Marion *et al.* 2006, Marion & Hockett 2008b, Wimpey & Marion 2011b). The increasing availability of high-resolution spatial data, such as LIDAR, has the potential to enable accurate trail inventory and mapping by trail feature extraction from spatial data in a Geographic Information System (GIS) environment instead of field surveys (Kincey & Challis 2010, Marion *et al.* 2012). More exploratory work in this area is needed.

Advantages of census surveys include the ability to produce maps showing the location and spatial arrangements of informal trail networks, document the number of trail segments and aggregate lineal extent, perform GIS analyses to investigate proximity to rare flora or fauna or sensitive environments, evaluate landscape fragmentation, and perform other relational analyses. Aggregate lineal extent, area of disturbance, trail width, and landscape fragmentation indices are some examples of informal trail impact indicators that GPS/GIS-based trail mapping can provide (Leung & Louie 2008, Marion *et al*. 2006, Wimpey & Marion 2011a).

Resource conditions along informal trails can also be assessed to document effects on vegetation and substrates. A common method is to assign a condition class rating, generally five categories describing increasing levels of trampling impact from a faint trace to a barren and eroded tread (see examples in Manning *et al.* 2006 and Marion *et al.* 2012). Informal trails are broken into separate segments whenever condition classes change categories. Other tread condition indicators such as width and depth, and inventory indicators such as trail grade and vegetation type, can also be assessed using ratings and input as attributes of these segments (Rochefort & Swinney 2000, Marion *et al.* 2012). Resource condition assessments recorded for trail segments generally employ "typical" or categorical range data representative of the entire segment, resulting in some inaccuracies because these assessments are generally not measured. More accurate measurements can be taken using a point sampling approach, generally employing a fixed interval between points with a random start. This method was employed by Wood and others (2006) to characterize informal tread width, depth, cross sectional area soil loss, and estimated total area of disturbance in Shenandoah NP.

In locations that receive sufficient traffic to remove vegetation and soils, another technique can be applied to provide highly accurate data on changes to vegetation and soils. Permanently referenced line transects can be established to measure groundcover conditions and soil height, with subsequent measurements to monitor long-term changes. Leonard & Whitney (1977) provide an early protocol for assessing such impacts to trails. Their technique employed placement of galvanized nails driven into trees on opposite sides of the trail, with a leveled taut line and fiberglass tape measure stretched tightly between them. Using a plumb bob on a line, vertical distances from the taut line to the ground surface are then accurately measured each 5 or 10 cm along the line and assessments of groundcover characteristics around the plumb bob point. The vertical and horizontal measures allow computation of the cross sectional area between the taut line and the ground surface (Leonard & Whitney 1977).

An improved protocol was developed by Stuart Clement Solutions (2010) to monitor impacts on a mountain bike trail in Australia. Pegs are driven in nearly flush to the ground surface on opposite sides of the trail at sample locations. Tripods are set up to level a straight aluminum beam positioned perpendicular to the trail and over the pegs. A plumb bob is used to reestablish the height of the beam above the pegs, which have a hole drilled to mark the reference point. Instead of taking vertical measurements every 5-10 cm the Variable Interval Cross-Sectional Area (CSA) Method described by Marion and Olive (2006) was applied. This method improves accuracy and efficiency by taking vertical measurements only at points that best characterize the micro-topography of the ground surface along the transect (e.g., measures are closely spaced where the topography is rapidly changing, less so when topography is homogeneous).

Monitoring Impacts from Dispersed Off-trail Traffic

Monitoring visitor trampling impacts from dispersed off-trail traffic at levels insufficient to create continuous informal trails or recreation sites presents even greater impact assessment difficulties. Protected area managers and scientists generally focus their attention on more heavily impacted locations so protocols have not been developed or applied to assess the impacts of low levels of dispersed traffic. The authors recently completed research at Denali National Park where the impacts of low levels of dispersed traffic were of interest. However, even in this study the assessment protocols were oriented to detecting the emergence over time of informal trail segments, frequently appearing as discontinuous or intermittent “traces” of lineal trampling impact (Marion & Wimpey 2011). Due to the exceedingly large areas over which the monitoring was to occur this study developed various types of sampling to more efficiently detect the emergence of these informal trails (Figure 5). For smaller areas, such as mountain summits at Acadia NP, a census survey of such trails provides more complete information and is sufficiently efficient. However, such methods are less able to document dispersed trampling at levels insufficient to create informal trails.

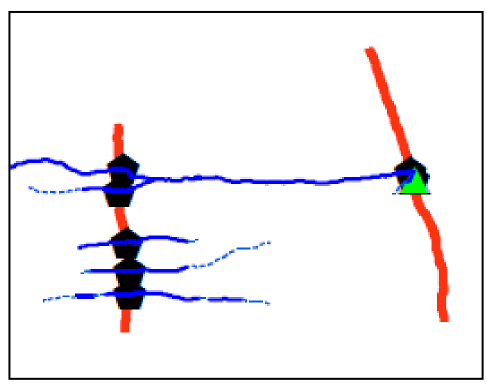


Figure 5. An efficient monitoring method developed for Denali NP involves walking line transects oriented perpendicular to the prevailing direction of travel by hikers (red lines). Informal trails (solid blue lines) and traces (dashed blue lines) were located and assessed at locations where they intersected transects.

STUDY AREA

The study area for this research was the Cadillac Mountain summit on the Mount Desert Island (MDI) portion of Acadia National Park, located on the Atlantic coast of Maine (Figure 6). This 68,940 acre glaciated rocky island includes 35,000 acres in park ownership (48% of the island). Park visitation was approximately 2.2 million visitors in 2009 (NPS 2009) with the busiest tourist season during summer (late June-August). Extensive networks of graveled carriage roads (non-motorized, multiple-use) and natural-surfaced formal hiking trails provide visitors with recreation opportunities throughout the park (Figure 6). The park's summits are particularly popular destinations because they afford scenic vistas of Maine's rocky coastline, the ocean, and offshore islands. As shown in Figure 7, visitors can drive to the summit of Cadillac Mountain to hike a formal summit trail, though open bedrock areas attract visitors off-trail to explore the summit, take photos, and enjoy the scenery.

Originally called Green Mountain, the summit was renamed Cadillac Mountain in 1918 to honor a French explorer who acquired Mount Desert Island in 1688 from the governor of New France. A cog railway ran from Eagle Lake 1.1 miles to the summit from 1883 until 1890, also accessing the Green Mountain Hotel located on summit (which burned down in 1895 and was not replaced). Current facilities on the summit include a small souvenir shop with restrooms, a large parking lot that accommodates both cars and buses, and an antenna array.

The bulk of Mt. Desert Island is comprised of intrusive igneous rocks, predominantly granites, with pink to greenish-gray coarse-grained granite on Cadillac Mountain, formed approximately 365 million years ago. This material was intruded into metamorphosed sediments known as the Ellsworth Schist, which were uplifted as mountains and then carved away and exposed through repeated cycles of glaciations between 1.7 million and 13,000 years ago (Maine Geological Survey 2011). Subsequent erosional processes have left the Cadillac summit with substantial patches of exposed granite interspersed with relatively thin patches of soils and low vegetation.

The principal plant community on the Cadillac summit is the Jack Pine Heath Barren, found on bedrock with thin and well-drained gravelly mineral soils (Lubinski *et al*. 2003). Tree species include *Pinus Banksiana*, *Picea mariana* and *Picea Rubens*, which are generally short and stunted. Heath shrubs are more common and well-developed: *Vaccinium angustifolia, Nemopanthus mucronata, Empetrum nigrum, Gaylussacia baccata, Kalmia angustifolia,* and *Photinia melanocarpa*. Common herbs, grasses, and sedges include: *Sibbaldiopsis tridentata, Cornus canadensis, Maianthemum canadense, Trientalis borealis, Deschampsia flexuosa, Oryzopsis pungens, Danthonia spicata, Carex pensylvanica,* and *Carex lucorumrum.* Non-vascular Cladina lichens are also common. Six floral species and two natural communities found on Acadia NP's summits are listed as rare by the Maine Natural Areas Program (Gawler and Cutko 2010).

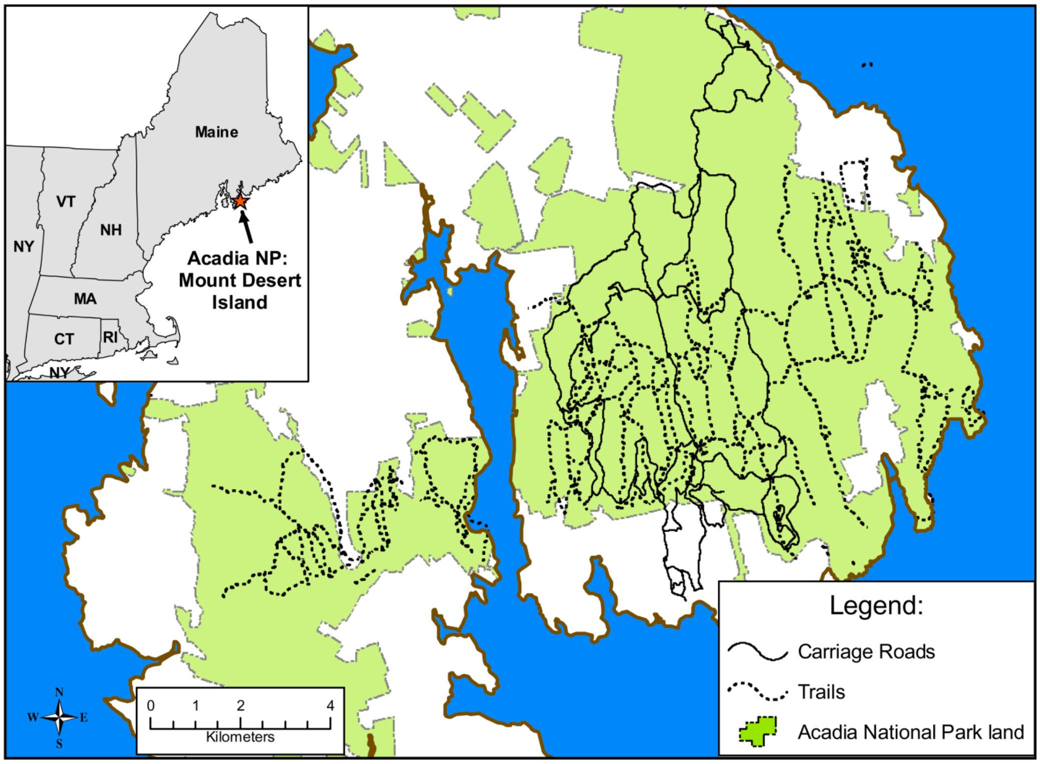


Figure 6. Acadia National Park, Mount Desert Island trails and carriage roads. The island has over 183 km of hiking trails within the park boundaries.

Figure 7. The Cadillac Mountain summit is glacially scoured granite interspersed with depressions containing thin soils and low vegetation. Note the paved formal loop trail and off-trail hiking activity visible in this photo.

The Cadillac summit, due to harsh growing conditions and thin soils, is a fragile sub-alpine environment that is neither resistant nor resilient to human traffic. Several globally to locally rare plant species are found throughout Acadia's granite summits and balds. Ecologist and author Tom Wessels has described the lichens of Acadia as more diverse and luxuriant than any other granite area in the U.S., and notes that the extensive mats of lichens and mosses are cryptogamic, and as fragile as their western counterparts (Wessels 2001).

Most mountain summits in Acadia NP lack natural physical barriers such as uneven bedrock, jumbles of large loose rocks, or dense vegetation that might discourage off-trail hiking. Visitors wander off formal trails, generally on bedrock surfaces, to seek a different view, a view-shed with fewer people in it, a photo opportunity, exploration, or to pick blueberries. Even when hiking trails across open granite are seemingly well-marked, hikers stray from the desired path because it's easy to do so and they can't easily get lost. Unfortunately, visitors frequently encounter and must cross patches of vegetation to link up with other areas of exposed bedrock, so vegetation and soil impacts are common on most summits.

As previously noted, summit visitation is estimated at more than 500,000 visitors/year. Such high visitation, combined with sensitive sub-alpine vegetation and thin erodible soils, has resulted in a number of significant trampling-related resource impacts (Figure 8). Once the thin veneer of vegetation is lost, soil erosion from wind and water can occur quickly, particularly of the upper organic layer. In contrast, the soil-building process on these exposed granitic summits requires many thousands of years. Furthermore, once soils are substantially lost, even in absence of recreational traffic vegetation returns at an extremely slow rate. There is clear evidence of this based on the limited vegetative recovery occurring within the exclosures (Figure 3) that park managers have erected on the summit. Thus, soil loss may be aptly termed a long-term form of resource "impairment," rather than considered a short-term recreation impact.

The loss of soil and vegetation from intensive recreational traffic and associated off-trail "wandering and exploration" behaviors is thus a principal concern for Acadia managers. An action item listed in the park's GMP (NPS 1992) to mitigate impacts from human use highlights Cadillac Mountain and other summits. Since 1997, ridge-runners sponsored by Friends of Acadia have roamed all the summits educating visitors about *Leave No Trace* principles, especially the need to stay on the trail and/or use durable rock surfaces. The results of this research will help inform and evaluate the efficacy of these efforts and future rehabilitation work.

Figure 8. Areas of untrampled pristine vegetation and soils like this can be found within 300 yards of the Cadillac Mountain Loop Trail. Note the diversity of plants, lichen, and moss that cover all of the soil and most of the rock. Below – areas of vegetation and soils impacted by off-trail trampling are common close to the Loop Trail. Note the visual evidence of substantial soil loss exhibited by the “bathtub ring” of exposed bedrock not yet colonized by lichen (see also Figure 3). While this suggests more recent soil loss from recreational traffic (e.g., last two-three decades), a substantial fire burned most of the summit vegetation in 1947 and it is possible that some of this soil loss occurred following the fire.

METHODS

Given the research objectives, we emphasized measurement-based assessment procedures that could be replicated with acceptable measurement error to provide data to accurately document changes in resource conditions over time. Based on our reviews of the literature and through discussions with park staff and among the research team we decided to develop protocols to document visitation-related impacts through three separate but related impact assessment protocols. These included: 1) an assessment of visitor-created informal trails, 2) an assessment of soil loss, and 3) an assessment of land cover (vegetation/groundcover) changes. The protocols developed for each of these are briefly described in this section, with more detailed procedures included in Appendices.

The following protocols were applied within a study area defined for the summit of Cadillac Mountain. Study area boundaries were determined through consultations with park staff, and were selected to include the more accessible and visited portions of the summit surrounding the summit parking lot and the 0.3 mile paved summit trail. The study area size was 17.5 acres (764,453 ft^2).

Informal Trail Assessment

All informal (visitor-created) trails within the summit study area were located and mapped using a Trimble GeoXT Global Positioning System (GPS) unit and Hurricane antenna, with post-processed differential correction of the GPS locations to achieve nominal one-meter accuracy (use of trade, product, or firm names does not imply endorsement by the U.S. Government). A data-dictionary within the GPS unit was developed and employed to assign each trail segment a condition class and average width. The five condition classes were defined as follows:

- **CC1:** Trail distinguishable; slight loss of vegetation cover and/or minimal disturbance of organic litter.
- **CC2:** Trail obvious; vegetation lost and/or organic litter pulverized.
- **CC3:** Vegetation cover lost and/or organic litter pulverized within the center of the tread; some bare soil exposed.
- **CC4:** Nearly complete or total loss of vegetation cover and organic litter within the tread; bare soil widespread.
- **CC5:** Soil erosion obvious; root exposure on trail edges; tread down to bedrock.

These protocols are designed to document the number, lineal extent, spatial distribution, area of trampling disturbance, and resource condition of all informal trails within the study area. Due to numerous areas of exposed bedrock, most informal trails were short and discontinuous. If periodically recollected over time, these data can assist with the monitoring of onsite resource conditions and provide long-term documentation of the existence, location, and condition of informal trails. The data also provide supporting information for management decisions, such as to evaluate which informal trails should be closed or left open, and later to evaluate the success of management efforts to close selected trails, prevent the creation of new trails, or prevent further deterioration of existing trails.

This collection protocol was applied July 18-25, 2008, and replications should be conducted at approximately this same time of year to maximize comparability. It is unlikely that informal trail conditions change very much on an annual basis so monitoring at 5-10 intervals may be sufficient, or perhaps 2-3 years after a corrective management action is implemented. The informal trail assessment protocols applied to the Cadillac summit were previously included as Appendix 2 in a management report to Acadia NP staff titled: Informal and Formal Trail Monitoring Protocols and Baseline Conditions: Acadia National Park" (Marion, Wimpey, & Park 2011). Therefore, these procedures are not included in this report. A newer set of informal trail assessment protocols developed based on extensive research in Denali NP (Marion & Wimpey 2011) are included as Appendix 1 to this report, and are recommended for consideration. See also other guidance and results in Marion and others (2011).

Soil Loss Assessments

Given the shallow lenses of soil that occur in the summit bedrock plant community and the extremely slow rate of soil formation, even relatively small amounts of soil loss can have substantial negative ecological consequences. Existing protocols applied to assess soil loss on trails were viewed as insufficiently sensitive, accurate, and precise (inconsistent) given the relatively thin soils and park monitoring interests for summits. A procedure able to document soil loss close to the one-centimeter range along permanently referenced transects was viewed as the principal goal of this work. A few core challenges for this work are addressed below and the full procedures are included as Appendix 2 to this report.

Given the extensive bedrock exposure on Acadia NP summits, the traditional use of metal stakes driven into the ground to serve as a permanent datum for measurements was not possible. A method able to permanently locate transect reference points on exposed bedrock *and* serve as an elevation datum for soil loss measurements was needed. The method we developed involved the relocation of transect endpoints marked by drilling 3/16th inch diameter holes into exposed bedrock on opposite sides of a selected lens or pocket of soil to be monitored. These points can be relocated using GPS units and ground-based digital photographs.

Another challenge was the inevitable downward "bowing" of any transect tape measure or line employed to serve as a fixed datum for measuring down to the soil surface along transects, which vary in length. To address this problem we developed a projected laser-level beam transect method able to reestablish a perfectly straight reference line of a known height above the bedrock surface at the locations of the drilled transect reference holes. This allows accurate measurements of cross-sectional profiles from the fixed permanent reference points through a series of vertical measurements at fixed intervals along each "laser-beam" transect to substrate surfaces. Subsequent cross sectional area calculations of soil loss and/or gain over time can be computed through comparisons with transect data from subsequent monitoring cycles.

Because measurement calculations require the vertical measures from the ground surface to the laser beam be at right angles, we employed a laser level that projected a dot and could be leveled (some lasers are "self-leveling"). The laser can be positioned on a sand bag or mini-tripod to allow fine adjustments in its placement. The laser beam is aligned directly above the reference points and the elevation of the ground along each transect is measured from the projected laser line. A tape measure extending from A to B establishes the measurement position along the transect. Note that while transect measures are made from the laser line to the ground surface, the calculated cross sectional area value for comparison to future measurements will be from "Profile Reference Line" in Figure 9. This is done because the laser may be established at a different height in subsequent measurements.

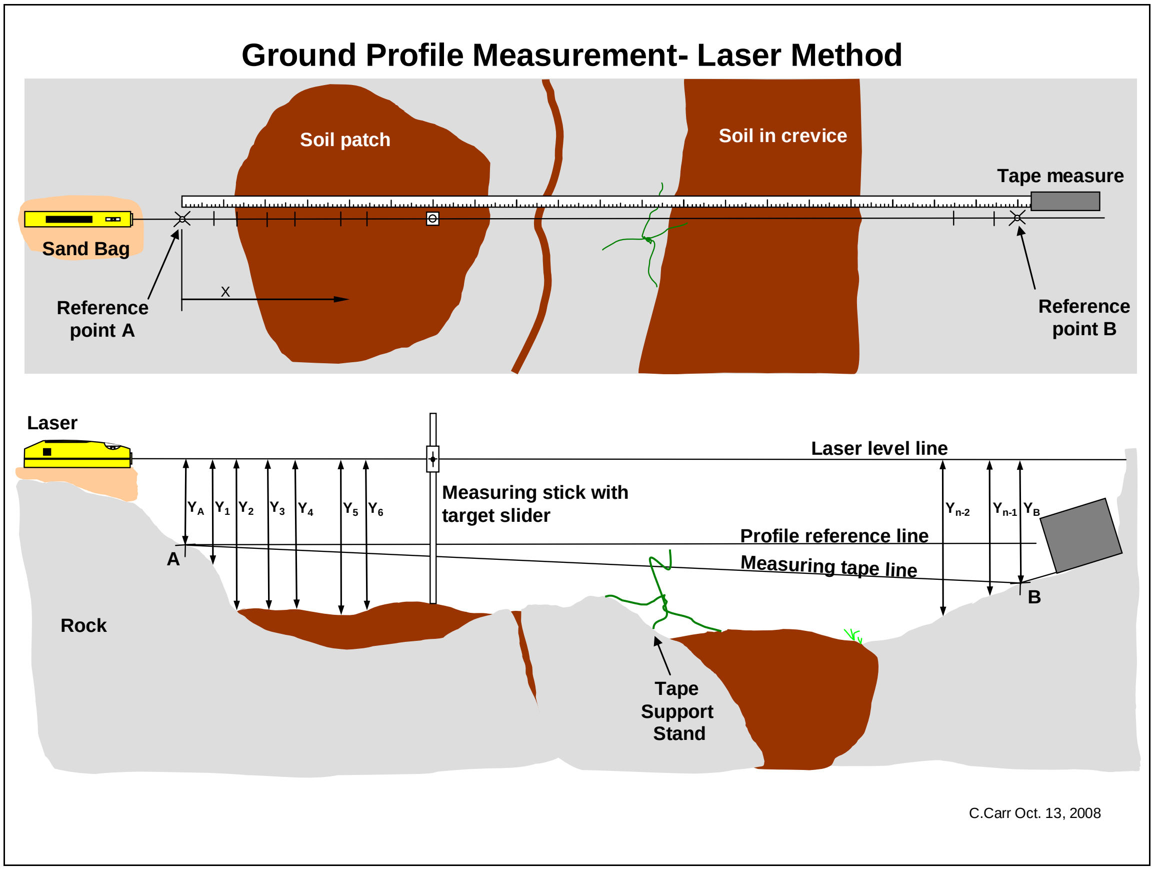


Figure 9. Overhead and profile views of the transect measurement system. Note the difference between the "laser level line", the "profile reference line" and the "measuring tape line."

This exploratory element of the study was conducted to develop and perfect soil loss assessment protocols and was applied at seven purposively located summit locations. Our goal was to select representative transects within two different summit areas: 1) we chose four transects in off-trail areas with intensive foot-traffic impacts, and 2) three transects located within fenced exclosure areas designed to prohibit further visitor traffic and allow recovery of previously eroded soils. These results are therefore *not* representative of the Cadillac summit, though they can be reassessed periodically to document the further loss or deposition of soil. The park can employ these refined protocols to reassess these seven transects and to establish additional transects for monitoring soil loss or recovery due to restoration or visitor management actions. A comprehensive manual titled "Monitoring Protocols for Assessing Soil Loss" (Appendix 2) provides detailed guidance for applying this measurement procedure, including improvements described in the Results section.

Summit Land Cover Assessments

This component of the research sought to develop efficient assessment protocols able to provide *representative* data to *document and monitor* trampling effects to the summit vegetation and soils from *intensive and dispersed* visitor trampling. This was the most challenging research component, primarily related to the difficulties of capturing a representative sample and documenting dispersed trampling impacts. Traditional plant ecology studies would generally apply multiple transects across the summit study area. However, transect vegetation and soil assessments are a very time-consuming process, require technical skills that park managers may have difficulty applying, and generally involve tape measures being placed across intensively used trails for extended periods of time. Similar problems are associated with quadrat sampling, though selecting and locating them through GIS and GPS technologies eliminate conflicts with visitors and the need for tape measures.

Photographic methods for capturing and documenting vegetation and soil conditions were carefully evaluated in lieu of direct field assessments due to their high degree of efficiency in data collection and limited disturbance of visitor enjoyment of the high use Cadillac summit. This began with consideration of commercial satellite imagery: Ikonos images with spatial resolutions of 0.89m (Pan) and 4.0m (Multispectral) (Figure 10). Analysis of a 1m Hue, Saturation, and Value (HSV) Pan/Multispectral merge showed a lack of ability to discern small islands of vegetation. For example, the smallest individual feature we would expect to discern in this imagery/classification would be 3-5 pixels, about 3-5m^2, but generally much larger than this. This imagery is very useful on a park-wide scale, but for the scope/scale of the summit study it is not appropriate.

Aerial photography imagery was also evaluated: 1979 color infrared and 1997 color aerial photos were analyzed in the study area and show promise for creating classification maps (Figure 10). These have a spatial resolution of around 0.45m in both data sets. The smallest individual feature we would expect to discern in this imagery/classification would be 3-5 pixels, about 0.75-1.25m^2. Color infrared images are preferable for vegetation detection. A significant disadvantage is the ability to discern exposed soil patches from bedrock and detection of recreation trampling damage to vegetation and soils.

Ground-based high-resolution digital photography has been successfully used in other research studies to assess vegetative cover in range management condition assessments (Booth *et al.* 2005, Seefeldt & Booth 2006, Booth *et al.* 2006a & b, Booth & Cox 2008). Of equal merit was the possible advantage demonstrated in these studies of employing automated computer software evaluations of the collected digital images, in lieu of time-consuming and potentially imprecise human evaluations. Photos could be taken from cameras slid along tensioned cables temporarily erected across the summit, or from a mobile quadrat assembly with a pole and camera support arm. A principal advantage of ground-based photography is the ability to clearly discern and differentiate rock from exposed soil/gravel and trampling damage to vegetation.

Following discussions with park managers, we developed a research design to employ GIS, GPS, and ground-based digital photography technologies to sample, select, and locate quadrats, and capture images for human and computer-automated processing. A grid transect sampling method with quadrats was employed to obtain a representative sample of the Cadillac Mountain summit study area. Analyses of digital photographs using human subjects and automated computer software were employed to determine the relative percent cover of several ground cover classes, and to evaluate the potential benefits and efficacy of automated options.

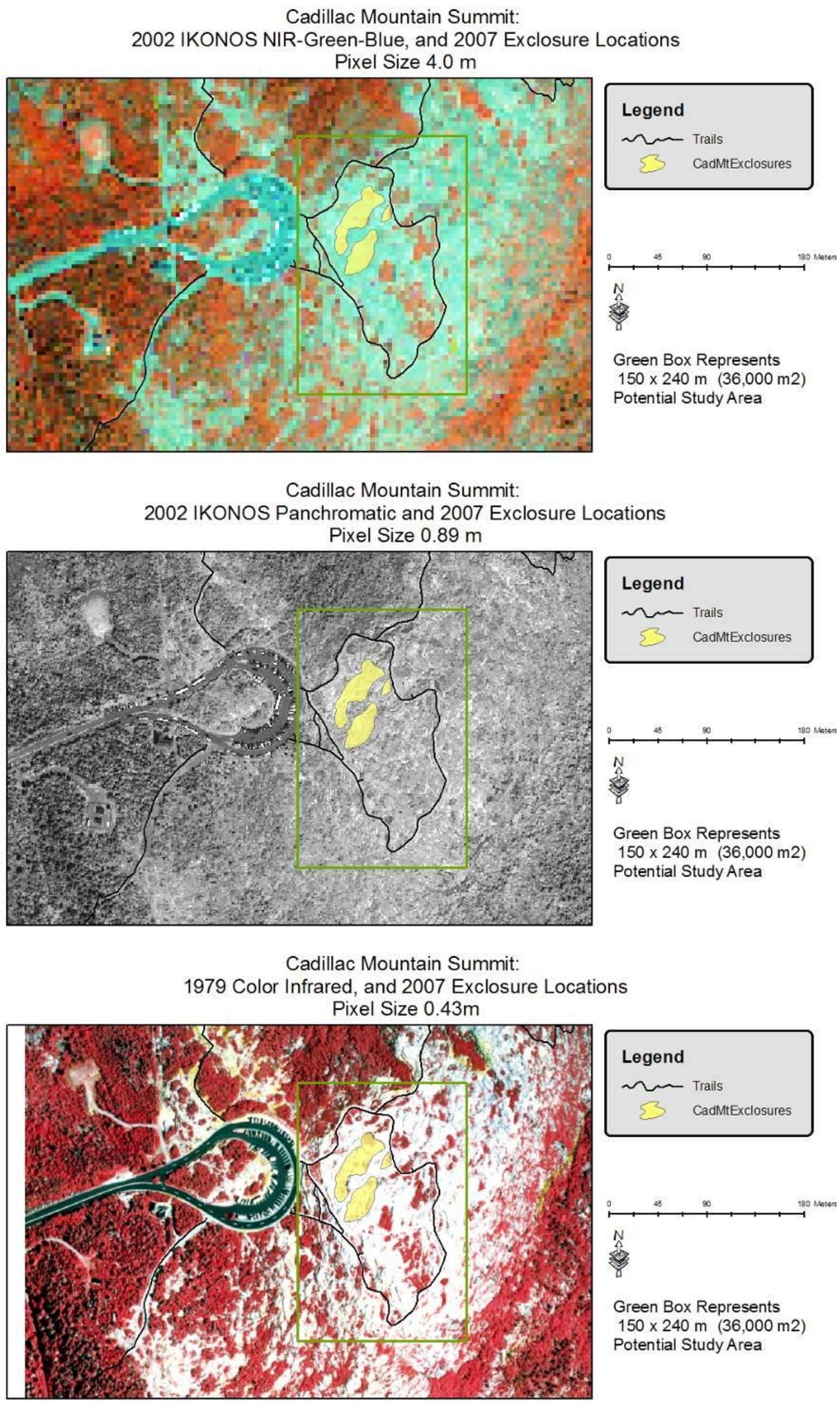


Figure 10. Ikonos NIR and Panchromatic and Color Infrared imagery for the Cadillac Summit.

Sampling Design

A statistical power analysis was conducted (alpha=0.05) to determine the sample size needed based on the area of the summit study area (71,020 m^2), and an oversample of at least 1% was added. Hawth's Analysis Tools extension for ArcGIS (Beyer 2007) was used to create a grid overlay for the summit study area polygon. A random (X, Y) shift was applied to the entire grid to ensure a random sample of points (15 m spacing) across the summit (Figure 11). The point coordinates were then loaded onto a Trimble GeoXT GPS to navigate to each sampling point on the grid, where an aluminum 1m^2 quadrat frame was placed to orient the taking of a high resolution digital photograph of ground cover.

Sample point quadrat photos were collected using a Nikon Coolpix P50 8.1-megapixel digital camera mounted on a post that positioned the camera for nadir (vertical perspective) images 1.4m above the quadrat and ground level (AGL) (Figure 12). The base of the frame was always oriented north-south with a compass and a digital photograph was taken at each point. Most photographs were taken under cloudy skies; when the sun was directly shining, a large fabric sunlight-filtering disk was used to eliminate highlights and minimize shadows.

The stratified random sampling provided a grid with 317 sample points. Upon visiting these points during fieldwork field staff discovered they were unable to set up the metal framed quadrat at 67 locations due to dense patches of tree and/or shrub vegetation (for example, see background area shown in Figure 12 photo). Placing and conducting our assessments at these locations would have damaged the vegetation and in many locations tall shrubs would have obscured capturing usable images. Even in areas with somewhat lower shrub cover, frame placement would have bent branches and provided variable images and data, and the lack of permanent rock reference features would have prevented the exact placement of the frame in the future, necessary to capture comparable imagery. Therefore, at these 67 locations we assessed cover ocularly at the sample point without using the metal frame. Careful inspection in each instance revealed no evidence of human trampling disturbance and 100% vegetation cover (one quad had 10% exposed rock).

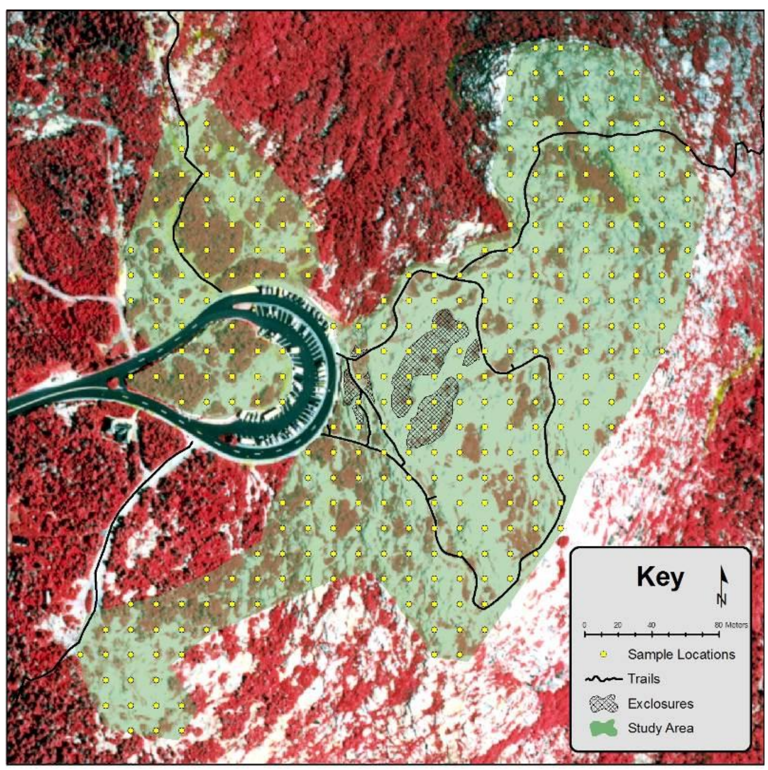


Figure 11. Cadillac summit study area, 71,020 m^2, showing the locations of 317 randomly stratified sample points.

Figure 12. Aluminum frame used to orient and take high-resolution digital photographs of each quadrat. On right, a representative quad photo. Note that photos can reveal clear differences between many categories of ground cover, including green lichen cover on bedrock, worn vegetation from trampling, and even recent soil loss (note tan-colored areas of bedrock).

We note that the presence of dense shrubs generally affords a high level of protection from visitor traffic. Omission of these locations increases monitoring efficiency while focusing monitoring effort and management attention on the remaining areas that have or are most likely to see potential future trampling damage.

Eleven quadrats were eliminated because they fell on a portion of the paved loop trail (n=8) or parking lot (n=3). Monitoring artificial surfaces was not a study objective. This left 239 quadrats from which digital images were obtained. Eight of these were within the fenced exclosures and 30 were within one meter of an inventoried informal trail. A high-accuracy reference point for each photograph was collected with the GPS unit to allow for future relocation of photo quads, along with the quadrat photos (original and cropped to within the frame) (see Figure 12) to aid in relocating and repositioning the quadrat during future monitoring efforts. We note that future monitoring efforts should strive to take photographs at the same time of year as our baseline assessments were conducted (July 18-20, 2008). Some adjustment for phenological stage may be needed based on examination of the photographed vegetation. Calculations of growing degree days (GDD) using Bar Harbor meteorological data (available online) may also be helpful.

Groundcover Assessments

Our original photographs were cropped to just inside the aluminum frame for all subsequent analyses. The original and cropped versions will be included on a data archive CD provided to the park, along with GIS layers and other project data. We applied and compared results from several methods of quantifying the relative cover of ground cover types.

Method 1: Estimates of trampling disturbance within the summit study area were derived from two components. As described previously, all informal trails within the study area were located and assessed with GPS units, recording the location, condition class, and average width of each segment. Total area of disturbance was computed by multiplying informal trail mean widths by their lengths. However, this computation does not capture trampling disturbance associated with more "nodal" areas of impact, or from dispersed traffic insufficient to create a visible trail. To compute the total area of trampling disturbance within the study area, project staff assessed the 239 digital quad images to record the percent cover of visually obvious trampling disturbance to vegetation, soil, or rock (e.g., lichen cover). This assessment included only vegetation cover with visible trampling disturbance (see Figure 12), all exposed soil (which is rare in undisturbed "control" areas), and bedrock surfaces that exhibited clear trampling damage to foliose or crustose lichen and newly exposed bedrock from soil loss attributable to visitor trampling (i.e., a "conservative" estimate). These were assessed and recorded separately. Cover data from the 67 sample points that fell into the shrubby patches were also included in this assessment

Method 2: Cover was assessed manually from all cropped images with the aid of a free computer software package SamplePoint (Booth *et al.* 2006a, http://www.samplepoint.org/). This software facilitates manual point sampling of digital images with up to 92% accuracy of cover estimates (Booth *et al.* 2006a). The program overlays a grid of 100 points on each image, and a trained staff person manually classifies each point by selecting one of the user-defined cover classification buttons located under the image. Each classification is automatically saved to a database in Microsoft Excel. Fourteen ground cover classes were included in the land cover classification: graminoids, shrubs, forbs, ferns, moss, rock, crustose lichens (thallus tight to the rock), foliose lichens (thallus separate from the rock), organic soil, mineral soil, organic litter, standing dead wood, shadow, and other. The "shadow" category denotes points that were unidentifiable due to shadows and lack of detail (e.g., dark areas under leaves or stems or in rock cracks); the "other" category denotes points falling on positions that could not be classified as any of the above. Guidance for assessing these categories are included as Appendix 5. Training of image assessors was conducted until the staff achieved a 95% correct rate.

Method 3: Cover was assessed independently by three project staff who viewed the 239 digital quad images and applied the classes described below. Procedures are included in Appendix 4. A grid printed on clear plastic was placed on the computer screen over the quadrats to assist staff in making consistent vegetation cover estimates (see Appendix 4). Groundcover categories and descriptions:

Woody – Mostly green woody vegetation (trees and shrubs). When in doubt vegetation was assessed as herbaceous cover.
Herbaceous – Non-woody mostly green vegetation cover, including mosses but not lichen.
Graminoids – Mostly green grasses and/or sedges.

Senesced/dead vegetation – Any predominantly tan-colored broad-leafed or grass-like leaves and/or non-leaf bearing woody stems.

Mosses – Include only mosses, noting that some may appear almost black in color and that some lichen are green.

Rock – Bare rock, often pink in color on Cadillac (rare without lichen cover).

Lichen – Rock covered by crustose or foliose lichen ranging in color from white, to green, to grey, including Reindeer lichen.

Gravel/Soil – Gravel is rock that is in loose form (e.g., 2-inch and smaller); this class includes all loose rock fragments and organic and mineral soil that tend to aggregate in the same areas.

Other – This class includes anything not covered in the other classes (e.g., man-made objects such as wooden stakes, rope, shoes, trash, etc.)

<u>Method 4:</u> Our final method employed computer image analysis software using the VegMeasure and ENVI software packages. VegMeasure is a software package developed by the Department of Rangeland Resources at Oregon State University to monitor rangeland and agronomic vegetation (Johnson *et al.* 2009). It provides an efficient and accurate automated method for measuring vegetation and land cover from digital imagery.

ENVI, developed by Exelis Visual Information Solutions, ENVI stands for “Environment for Visualizing Images.” This software package provides advanced spectral image processing that works with a variety of image types. Modules and image analysis tools within the software allow you to perform various tasks, including supervised (user guided) and unsupervised classification of land cover based on spectral characteristics.

RESULTS

Informal Trail Assessments

The 764,453 ft^2 Cadillac Mountain study area was carefully searched for informal trail fragments, which were mapped with a sub-meter accuracy Trimble GPS unit. A total of 323 informal trail segments were mapped, totaling 1.46 miles, about three times longer than the total length of formal trails within the study area (Figure 13). These trails are uniformly distributed throughout the Cadillac summit area and coincide with patches of vegetation, which they bisect to link areas of exposed rock. NPS signs posted throughout the summit area ask visitors to "Step on the paved trail or rocks" (see Figure 1), thus off-trail hiking is legal and not actively discouraged. However visitors may not recognize the difference between gravel soil and bedrock surfaces (Turner & LaPage 2002; Park *et al.* 2006), or may mistake informal trails as legitimate official footpaths.

Informal trails ranged in width from 8–84 in, with a mean of 25 in. Table 2 provides a summary of the informal trail condition classes for the Cadillac summit study area (see Methods section for definitions). The condition of informal trails was generally poor, with 76.5% of their total length classified as CC 3–5 (Table 2). Half of the 323 trail segments (50.1%) were assessed as CC 4 or 5, exhibiting significant impacts to vegetation and soils. Within the summit study area, informal trail treads directly comprised 17,188 ft^2, representing 2.2% of the study area.

Table 2. Summary of informal trail segments by condition class for Cadillac Mountain.

Condition Class	Number	Percent
CC1	37	11.5
CC2	37	11.5
CC3	87	26.9
CC4	85	26.3
CC5	77	23.8
Totals:	335	100

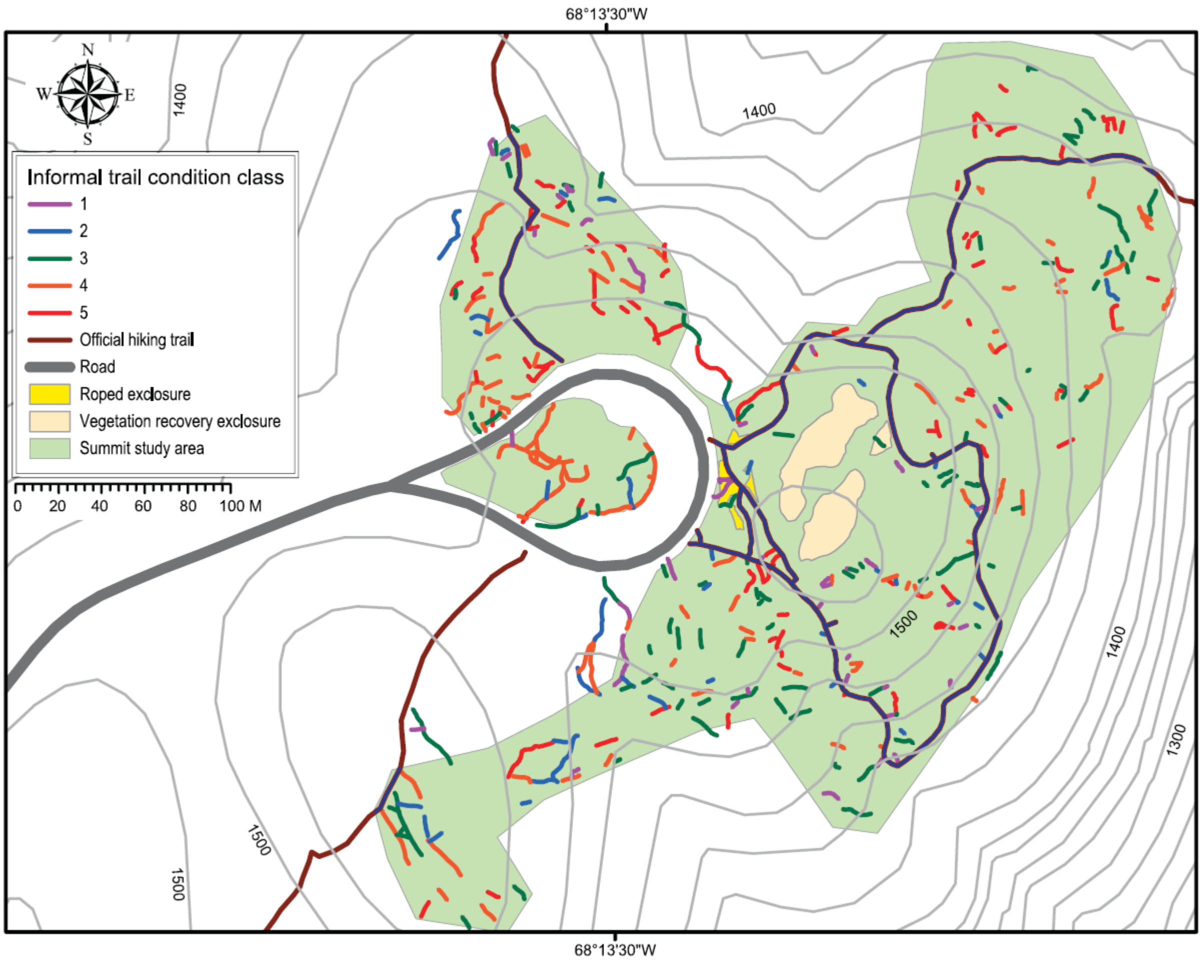


Figure 13. Cadillac Summit informal trail mapping by condition class.

Soil-loss Assessments

Results of the soil profile assessments document the vertical distance between the soil surface and profile reference transect lines (Figure 14). This procedure establishes an accurate and repeatable method for examining soil-profile changes over time, with repeated assessments that document subsequent soil loss or gain. Soil loss is an important aspect of recreation disturbance to natural areas, and many studies of both trails and campsites include estimates of soil loss. Soil loss is particularly critical in subalpine and alpine environments because of slow rates of soil development and the necessity of soil for plant growth. Recent advances in trail impact monitoring have included improved measurement procedures for examining the depth of incision along trails and for assessing volumetric measures of soil loss by using a cross-sectional area method (Olive and Marion 2009). The procedure developed here is a more accurate and sensitive version of the cross-sectional area measurements applied to trails. It would also be suitable for application in assessing substrate disturbance at sensitive archaeological sites in protected areas.

This section presents ground profile data from seven transects on the Cadillac summit, along with improvements to the measurement procedures. The transects were located as shown in

Figure 14. The full datasets collected from each transect, including field data sheets, a data graph, a stitched transect photo montage, and accurate GPS coordinates for each transect endpoint are included in Appendix 2: Soil Loss Transect Results and Calculation Guidance, and on an archive CD of all project data and photographs from this study. A spreadsheet file on the CD includes all profile measurement data in the format for plotting. The plots were produced with the Golden Software program called Grapher. The Grapher files are on the CD.

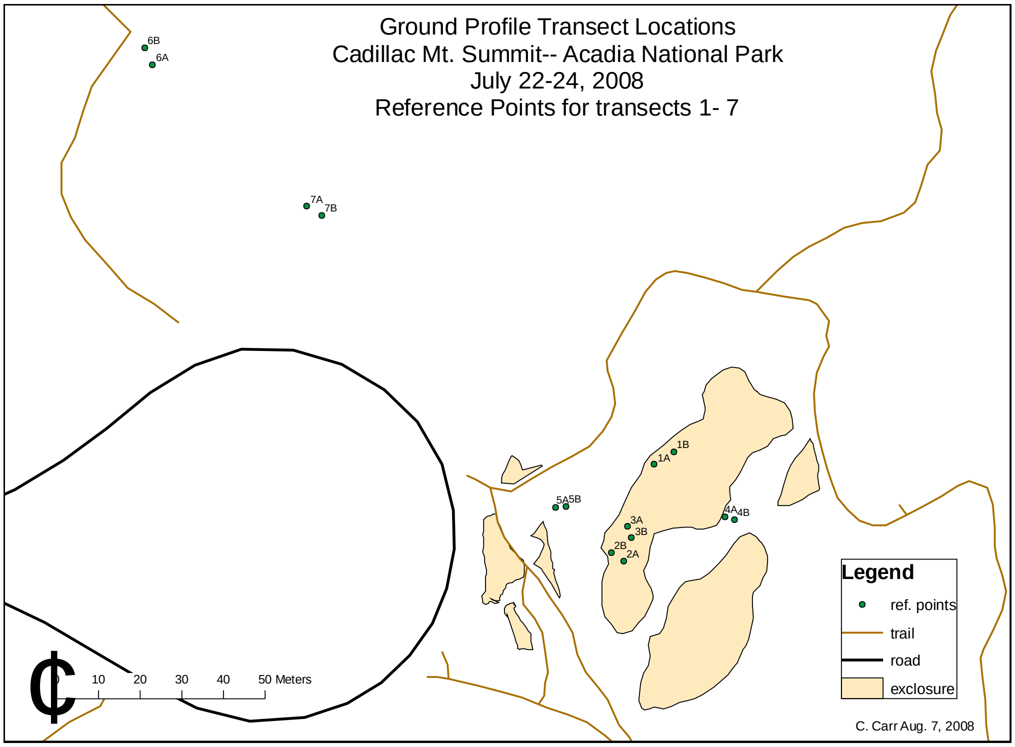
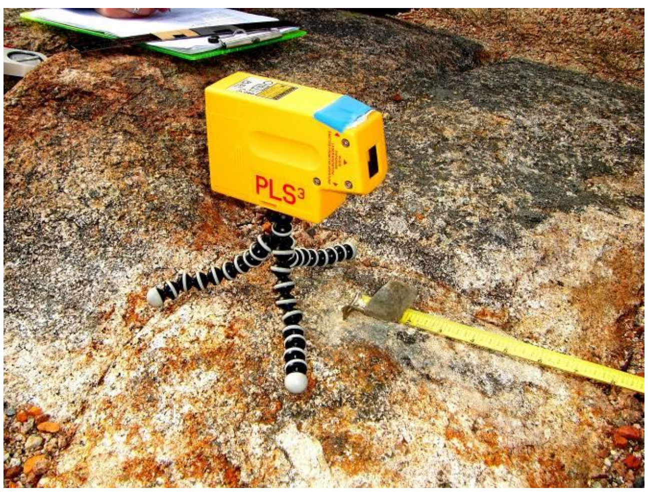


Figure 14. The location of the reference points marking the ends of the seven transects in relation to the summit area road and formal trails.

Transect	Location	Exclosure	Length (Cm)	Laser Used	Date
1c	East Summit	in	583.7	LSE	7/22/08
1k	East Summit	in	583.7	PLS3	7/22/08
2	East Summit	in	349.4	LSE	7/23/08
3	East Summit	in	278.0	PLS3	7/23/08
4	East Summit	out	219.0	LSE	7/23/08
5	East Summit	out	230.9	PLS3	7/23/08
6	North Summit	out	458.5	SP2	7/24/08
7	North Summit	out	407.7	SP2	7/24/08

A typical transect is shown in Figure 15. This image is a merge of twelve digital photos taken along the length of the first transect (T1). The twelve images were joined using the photomerge tool in Adobe Photoshop. A full resolution copy of the merged image, and the individual images comprise it, are included on the report's archive data CD. The overall and reference point photos are needed to relocate the reference points for transect re-measurement. The photo merge was created in PhotoShop using the “create photo merge” tool. Note: uncheck the “snap to image feature” and use the move and rotate tools to align individual photos. It is best to align the photos based on the tape measure numbers (rather than background surface features). With parallax and other issues, the merge is only an approximation of the transect. Detailed examination of the surface along the transect should be done using the individual un-merged photos.

Figure 15. Transect photos. Above: transect 1 photo merge with laser on the left and the tape measure running from reference point A on the left to reference point B on the right (just ahead of the sand bag). Below: laser situated over reference point A, with close-up of the drilled reference point on right.



For transect one, both a Pacific Laser System PLS3 (shown in Figure 15) and a LSE laser level were used to generate the “laser level line.” Figure 16 is a graph of the profiles from the measurements using the two different lasers. The two sets of measurements were taken less than an hour apart so there should be no soil loss or deposition depicted. The two profiles should be the same. In particular, note the deviation in substrate profiles at 138 cm along the transect. The pendulum laser readings show a substantial drop in the profile. This was due to an error in reading the distance from ground to the “laser level line.” At this point the laser lines are recorded as 32 and 58 cm above the ground. We had not anticipated distances this long so our measuring stick was too short, and our improvisation led to one or both measurements being in error. The revised procedure manual (Appendix 1) specifies a longer measuring stick and ruler.

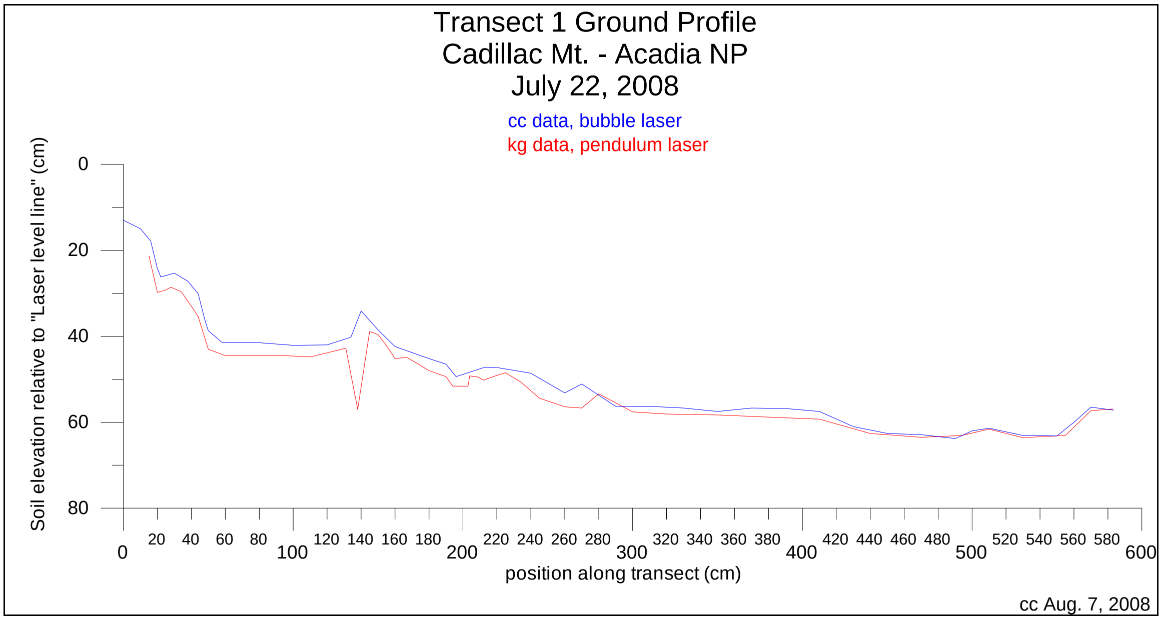


Figure 16. Two measurements of transect 1 before adjustment for difference in height of laser, for difference in level, and for a measurement error at 138 cm.

Other, more subtle differences are also present. First, note the pendulum laser graph does not start at the zero end of the transect—the first point is about 20cm over. This is because we positioned the laser over reference point A, therefore the height at A could not be measured. The revised manual specifies for the laser to be positioned behind reference point A.

There are also subtle differences in the height of the laser line above reference point A and in the level of the lasers. At the A or left end of the transect (Figure 16), the profile from the bubble laser is higher than from the pendulum laser. Assuming the distance from the laser line down to the Reference hole A is measured (Y_A in Figure 9), this difference is easily corrected in subsequent data calculations. It also appears the level of the bubble laser tips down relative to the level of the pendulum laser (the bubble laser elevations are above the pendulum elevations on the left end, but almost the same on the right end). By knowing the Y_A and Y_B measurements for both sets of readings, this difference in base level can be corrected.

Figure 17 shows the two transect one profile plots brought to a common level, a common elevation datum and the reading at 138 cm is deleted. The pendulum level was assumed to have the correct level. The bubble level data were adjusted to match the level of the pendulum laser, based on the difference between Y_A and Y_B; calculations are included in Appendix 2. The elevation of both sets of measurements was adjusted based on setting the elevation at reference point A to zero. The x-position along the transect was also adjusted based on the slope of the “measuring tape line.” The reading at 138 cm for the pendulum laser was determined to be in error by examining the vertical photos of the transect (see CD photos, transect T-1). The photo shows relatively level ground in this region, no dip as the data indicated, so the 138 cm height measure was omitted.

The two plots (Figure 17) are now in closer agreement. Note the y-axis is now labeled “Soil elevation relative to ‘profile reference line’”—this is the new elevation reference. The two plots now start together at zero on the y-axis and end at the same height - they were forced to do that by the datum and level adjustments. However, differences still remain as it is difficult to make measurements to this level of precision in the field. Some of the remaining differences are due to making measurements at different points along the transect. The revised manual specifies making repeat measurements at the same x-positions along the transect (with the option to add measurements when needed).

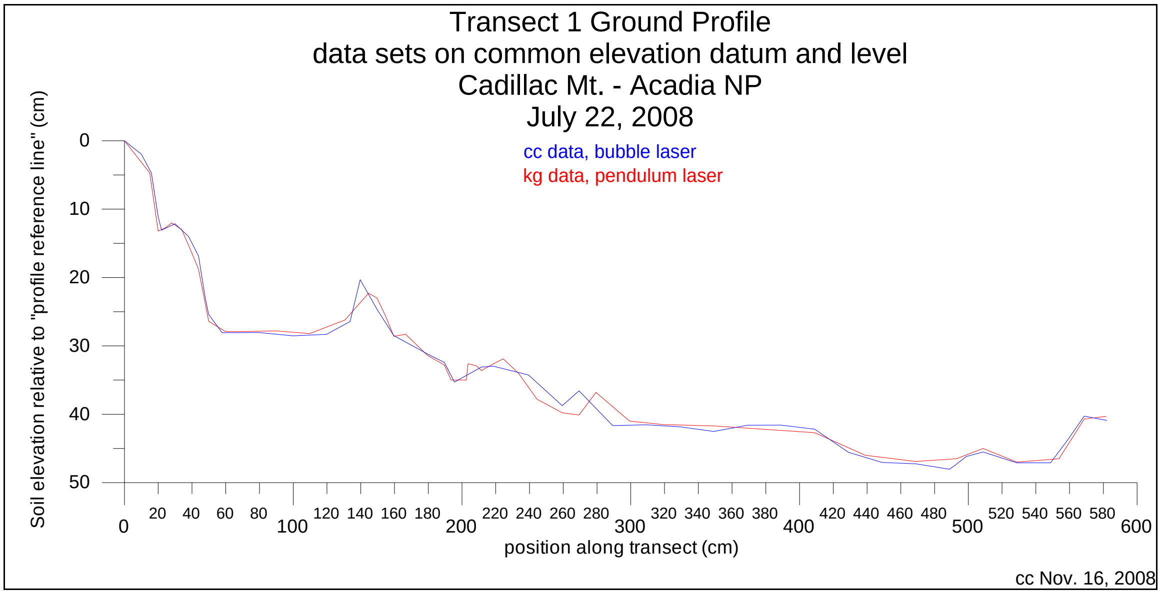


Figure 17. The adjusted transect one plots.

The base line profile for transect two is shown below (Figure 18). This plot has not been corrected for level or elevation datum. That correction will wait for a second set of measurements. The remaining base line plots are in Appendix 2, along with the raw data for the plots, the ground substrate along the transect (rock, vegetation, litter, organic soil or gravel), the photo numbers of the transect and transect descriptive measurements (e.g. transect length, orientation, and fall line slope).

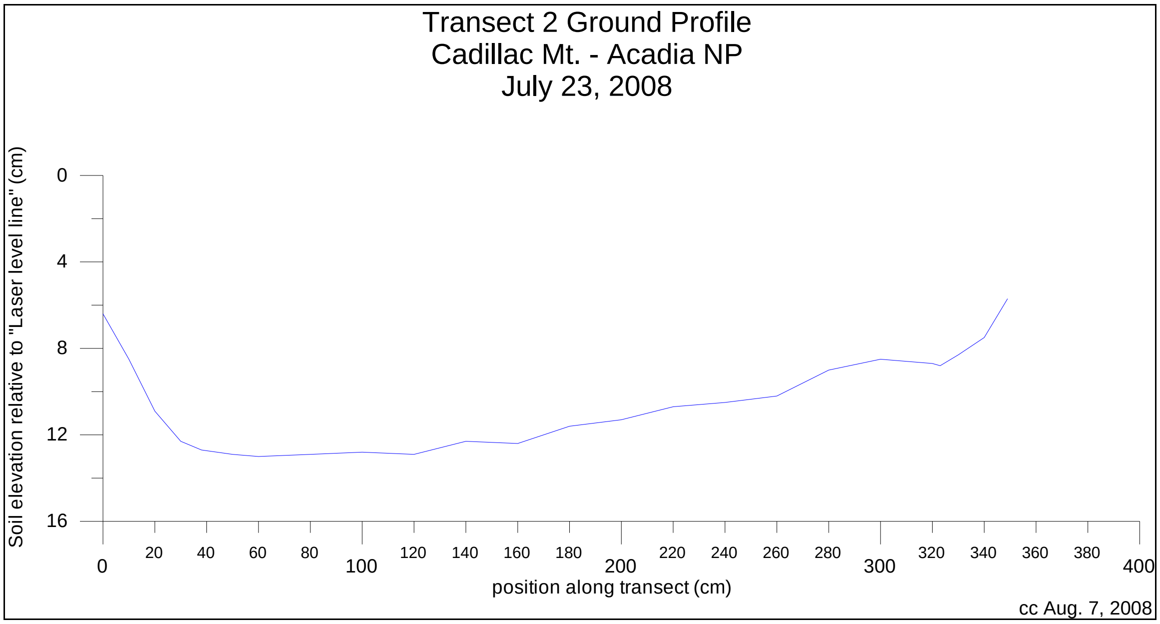


Figure 18. Baseline profile—not corrected for level or elevation.

Procedure Improvements

Based on the experience measuring these seven transects, a series of revisions were made to the procedures. The revisions include recommending the pendulum laser, positioning the laser behind A, use of a longer measuring stick, reference point B on a horizontal surface, vertical measurements made at same x-positions, simplified data sheets, and taking more care in measurements.

Pendulum laser: while the pendulum laser costs more and is more fragile than the bubble level, its advantages likely outweigh the disadvantages. The key advantage of the pendulum is easier set-up. Within limits, it is self-leveling. This feature means that it is faster to set-up and less skill and attention is needed for accurate data collection. This should more than pay for the additional cost (but the laser does need to be periodically checked to insure its self-leveling remains within specifications).

Position laser behind A: the laser should be positioned behind reference point A. This positioning allows Y_A to be measured. Pendulum lasers generally have a beam that shoots straight down. It is tempting to use this beam to position the laser directly over reference point A, but doing this precludes accurate measurements from this point to the laser line.

Measuring stick: The measuring stick has two advantages for measuring the y-dimension over the use of a ruler or tape measure. The first advantage is safety. When the measuring stick is made of wood it is less likely than a shiny ruler to reflect the laser beam into your eyes (causing retina damage). The second advantage of the measuring stick is repeatability of y-dimension measurements. The measuring stick has a small round footprint. This footprint insures consistent positioning over uneven surfaces. An earlier version of the procedures suggested direct measurement with a ruler. The long narrow footprint of a ruler can make positioning it directly under the laser beam difficult. The round base of the measuring stick may allow for more consistent positioning in soft substrates (e.g., wet or dusty).

Horizontal surface for B: Reference point A will always be on a horizontal surface (i.e., with a vertical drill hole). Occasionally B could be on a vertical surface. For consistency, it is better to use the same procedure to locate and mark all the reference points—therefore select all reference points on roughly horizontal surfaces. Additionally, by keeping B on a horizontal surface, the hole is visible in the vertical stitch photographs and the "laser level line" can be at any height.

Re-measure at same x-positions: Using the same x-positions will make it easier to analyze differences between plots. For re-measurements it is an option to measure at additional x-positions, just be sure to measure at all the original positions.

Data sheet simplification: A revised transect data sheet is organized in a more logical order and fitted to one sheet. This should make for smoother field operations and data recording.

Take more care: Measuring at this level of precision can be challenging. Time and care should be allocated to the task. The improvements to the procedures and tools should allow more focus on quality measurements.

Profile Calculations

In order to plot and compare profiles of the same transect, three adjustment calculations are needed. These adjustments are made under the assumption that the laser used in later measurements will not be placed at the same height as the first laser, and that one or both of the lasers may not be precisely level.

The first adjustment brings the x-measurements along the sloping "measuring tape line" to a horizontal reference. This is a simple matter of multiplying the cosine of the slope of the line by the x-measurement (see sketch and equations in Appendix 2).

The second adjustment brings the y-measurements down to the elevation of reference point A. For this adjustment Y_A is subtracted from each y-measurement.

The third adjustment accounts for differences in level. If the two lasers agree on level within tolerance, this correction is not needed. The two lasers agree on level if

$$Y_{A1} - Y_{B1} = Y_{A2} - Y_{B2} + \text{error},$$

where error < 0.3 cm.

If the laser level is out of tolerance, the y-measurements are adjusted based on the tangent of the angle between the respective "laser level lines".

The "profile adjustment procedure" is at the end of Appendix 2. The procedure shows how to convert from $X_{measured}$ and $Y_{measured}$ to $X_{horizontal}$ and $Y_{corrected}$. The sketch defines the variables. The corrections are based on the transect length and the initial and final Y_A and Y_B. The data CD contains a spreadsheet that makes the correction for the two sets of readings along transect one.

The data CD also contains GIS layers of the transect area, including a layer of the reference point locations. A tabular list of the reference point locations (Appendix 2) is also part of the data sheet spreadsheet.

Summit Land Cover Assessments

As noted in the Methods section, we employed four methods for assessing summit groundcover within the Cadillac summit study area. In this work, we sought to develop and refine procedures that park staff could periodically apply as part of a long-term monitoring program, or to evaluate the efficacy of future management actions applied to reduce off-trail trampling impacts. Project staff, in consultation with park managers, settled on a GIS-based random stratified sampling procedure to select representative sample points arrayed across the study area (Figure 11). Sample point coordinates were loaded onto Trimble GPS units used by field staff to locate each point and set up an aluminum frame with camera mount for taking digital images within the 1x1 m^2 quadrat (Figure 12). Fieldwork was therefore very efficient, requiring parts of three days.

<u>Method 1:</u> Managers seek to protect the fragile subalpine summit vegetation from visitor trampling yet Cadillac Mountain is a primary visitor destination, with an access road and large parking lot. Current visitor management policy for the summit asks visitors to "Step only on the paved trail or rocks and avoid plants and areas of bare soil" (Figure 1). If visitors adhered to this guidance there would be no visible trampling-related disturbance to summit vegetation and soils, though lichen cover on bedrock could be affected.

The efficacy of the current visitor management policies for this site can be examined by assessing the nature and extent of off-trail trampling disturbance within the study area. Our inventory of informal trails created by visitors (presented above) found 323 segments totaling 1.46 miles with a disturbance "footprint" of 17,188 ft^2. This represents 2.2% of the study area but trails could only be mapped within areas that have soil and vegetation cover. Also note that this assessment omits trampling disturbance associated with non-linear "nodal" areas of impact, or from dispersed traffic insufficient to create a visible trail.

A more comprehensive procedure was therefore applied by examining the 239 quadrat images for visible trampling disturbance. Data from this assessment are presented in Table 3, including data from just the 239 photo quads, and in the right-hand columns, data from the photo quads *and* from the additional 67 sample points located in shrub patches where quadrat images were not taken. The best and most representative data are from the combined photo and non-photo points. These data reveal that 12.6% of the summit study area (16.1% for photo quads only) shows visible trampling disturbance to vegetation, soils, and bedrock. While 5.9% of the quads had visible trampling disturbance exceeding 70%, 69.3% had less than 10% disturbance (Table 3). As noted in the Methods, estimates were made separately for visible trampling-related disturbance to vegetation: 1.8% (2.3%); soil: 6.0% (7.7%); and bedrock: 4.8% (6.1%) (#'s in ( ) are for just the photo quads). Note that the informal trail assessments estimated visitor-trampling impact to the study area at 2.2%, but this estimate excluded the exposed bedrock areas where it was impossible to discern and map trails. Summing only the vegetation and exposed soil categories of the visible trampling disturbance method (1.8 + 6.0 = 7.8%) provides a more comparable and appropriate estimate of visitor-trampling disturbance to the study area. This also indicates that an additional 5.6% of trampling disturbance within the study area is attributable to dispersed traffic located off the informal trails (7.8% -2.2% = 5.6%).

Table 3. Frequency distribution of estimated visible trampling disturbance to vegetation, soils, and bedrock from examination of 239 photo quads and combined photo and non-photo sample points.

Visible Trampling Disturbance (%)	Photo Quads		Photo & non-Photo Points	
	Count	Percent	Count	Percent
<10	145	60.7	212	69.3
10-19.9	36	15.1	36	11.8
20-29.9	16	6.7	16	5.2
30-39.9	7	2.9	7	2.3
40-49.9	7	2.9	7	2.3
50-59.9	7	2.9	7	2.3
60-69.9	3	1.3	3	1.0
70-79.9	3	1.3	3	1.0
80-89.9	3	1.3	3	1.0
90-100	12	5.0	12	3.9
Totals	239	100	306	100
Mean Values		16.1		12.6

Methods 2 and 3: Literature reviews revealed the SamplePoint software to provide the most objective and accurate procedure for assessing vegetation cover from our digital quadrat imagery. We acknowledge the contributed work by Kelly Goonan, a collaborator and graduate student from the University of Vermont, who developed and supervised the application of SamplePoint cover assessments of the 239 Cadillac Summit quadrat images. This method involves selecting and assessing cover for 100 points on each of the 239 images, so it is somewhat time-intensive. For this reason, we also had three project staff independently assess the images on computer screens, with grid overlays to improve assessment the accuracy of cover assessments. The SamplePoint procedure required about 6-8 minutes to apply for each photo while the grid overlay procedure took approximately 1 minute.

Table 4 presents the mean cover estimates derived from the SamplePoint procedure. While 14 categories of cover were assessed, results reveal that several categories were sufficiently rare (≤ 0.5%) that they could be combined with others unless there is a particular management interest, including: fern, litter, foliose lichen, and organic soil, dead wood, and other. This procedure does provide a structured sampling-based method for estimating quadrat cover from digital images. However, we note that these cover estimates, with the exception of mineral and organic soil, do not differentiate “trampled or disturbed” attribute cover from “untrampled or pristine” conditions, likely necessitating the procedures implemented in Method 1 above. Note that these data exclude the 67 sample points occurring in dense shrubby patches. The cover estimates for these 67 points lump all types of vegetation cover so combining the SamplePoint vegetation cover categories would be necessary to obtain more representative land cover values for the study area.

Next, we sought to develop a more efficient method for estimating cover from the quadrat imagery. We eliminated the rare attributes (≤ 0.5% cover), but retained the "Other" category in case it was needed. We also developed and refined some descriptive guidance for each category to improve consistency between raters (see Methods section). Results from having three project staff independently apply this onscreen cover assessment protocol are presented in Table 4. First, note that the "Other" category was largely unused and can be eliminated. Comparison of the averaged cover estimates for the three staff reveals reasonably good agreement for all but the rock and lichen attributes, and to a lesser extent, senesced vegetation. As described in comments included below the table, the combining of several attribute categories assessed by the SamplePoint procedure allows reasonably good comparability between the SamplePoint procedure and the more efficient grid procedures (Table 4). As for the SamplePoint procedure, these data exclude the 67 sample points occurring in dense shrubby patches. The cover estimates for these 67 points lump all types of vegetation cover so combining the vegetation cover categories would be necessary to obtain more representative land cover values for the study area.

Table 4. Mean cover assessments for 14 attributes based on sampling 100 points/image using SamplePoint software.

Attribute	Quadrat Cover (%)
Shrub	15.4
Forb	5.5
Fern	0.0
Graminoid	7.1
Litter	0.5
Mosses	0.6
Rock	14.3
Crustose Lichen	46.1
Foliose Lichen	0.1
Mineral Soil	8.6
Organic Soil	0.5
Shadow	0.6
Dead wood	0.1
Other	0.1

We summarize our findings for each attribute:

Woody Vegetation: There was strong staff agreement for this indicator, with a standard deviation of 1.3 on a mean of 16.8. There was also excellent agreement with the SamplePoint estimate of 16.1%. This was somewhat surprising as it was often difficult to discern the difference between low shrub cover and herbaceous cover. These two categories could likely be combined to eliminate this problem unless there is a management interest in distinguishing between them.

Herbaceous Vegetation: There was also strong agreement between the staff and SamplePoint cover estimates for this indicator, ranging from 5.0 to 6.0.

Graminoids: Cover estimates for this indicator were close but diverged somewhat, with a range from 3.5 to 7.1. There is little risk of mistaking grasses or sedges from any other type of vegetation but estimators expressed some confusion over distinguishing green vs. dried out grasses (assigned as "senesced," or "litter" in SamplePoint). It is also likely that some staff performed their estimates on the core tufts of grass clumps while others produced larger estimates based on the full spread of grass leaves.

Senesced: This category should likely be eliminated. It was most commonly applied to dried out grasses but there were gradations from fully green to fully dried out clumps that reduced the precision of our estimates. Further, the grasses assessed as senesced were in that condition due largely to their phenological stage and/or drought, rather than as a result of trampling disturbance. Thus, there appears to be little value in including this attribute.

Mosses: There was strong agreement for between the staff and SamplePoint cover estimates for this indicator, ranging from 0.6 to 0.9.

Rock: There was poor agreement for this attribute due to difficulties distinguishing bare rock from lichen-covered rock. Even in heavily trampled areas the crustose lichen often survive, though with somewhat reduced cover and a "worn" appearance if examined closely. If it is necessary to distinguish rock from lichen then we suggest that the SamplePoint procedure provides the optimal method for accurately assessing and distinguishing rock and lichen-covered rock.

Lichen: Crustose lichen on rock was clearly the predominant ground cover class on the summit. However, the randomly dispersed and clumped nature of lichen growth makes it difficult to accurately and precisely (consistently) differentiate lichen cover from bare rock.

Gravel/Soil: There was strong agreement for between the staff and SamplePoint cover estimates for this indicator, ranging from 8.2 to 9.2. The only potential problem for this assessment is when to assign the cover of non-bedrock rocks to this category. We arbitrarily set this as 2-inch and smaller. Exploration and searches in untrampled "control" areas found soil exposure to be quite rare so the presence of this attribute is the single best indicator of visitor trampling disturbance.

Table 4. Mean cover assessments for nine attributes based on onscreen cover estimates applied onscreen with a grid overlay to improve accuracy.

Attribute	Quadrat Cover (%)				
	Staff 1	**Staff 2**	**Staff 3**	**Staff Mean (St. Dev.)**	**SamplePoint**
Woody	17.7	17.4	15.2	16.8 (1.3)	16.1
Herbaceous	5.6	5.0	6.7	5.8 (0.9)	5.5
Graminoids	5.4	3.5	3.7	4.2 (1.0)	7.1
Senesced	1.0	1.9	4.3	2.4 (1.7)	0.5
Mosses	0.7	0.9	0.7	0.8 (0.1)	0.6
Rock	6.8	7.8	18.6	11.1 (6.5)	14.5
Lichen	54.6	54.1	41.8	50.2 (7.3)	46.4
Gravel/Soil	8.2	9.2	8.9	8.8 (0.5)	9.1
Other	0	0.2	0.1	0.1 (0.1)	0.1

Note: Several SamplePoint categories were combined to facilitate comparisons: forb and fern = herbaceous, foliose and crustose lichen = lichen, organic and mineral soil = gravel/soil, shrub and deadwood = woody, litter = senesced, and shadow was combined with either woody or rock, whichever had highest cover (photos consulted on some).

Method 4:

The VegMeasure software program yields a binary set of vegetation cover (white) and non-vegetation (black) measures for each quadrat (Figure 19). For the 239 quadrat images analyzed, vegetation cover ranged from 0.1 to 96.1% with a mean of 27.8%.

Figure 19. VegMeasure assessments provide binary cover assessments for vegetation cover (52.3% in this image) and non-vegetation cover (47.6%). Image not from a study quadrat.

The ENVI software was applied to a set of six test photos selected to evaluate the procedures in assessing different groundcover types (four are shown in Figure 20 on the following two pages). The capabilities of ENVI were explored through iterative experimentation and assessment with supervised and unsupervised classification employing four and five classes. The best results achieved with supervised classification are shown in Figure 20. However, examination of the images and classification reveal some substantial problems. In vegetated areas, shadows (blue) are distinguished from vegetation but classified the same as the darker lichens and exposed soil. More importantly, lighter-colored exposed soil (red) is classified the same as greenish lichen. Difficulties in accurately distinguishing different groundcover categories in this exploratory work led us to abandon further application to the full set of quadrat imagery.

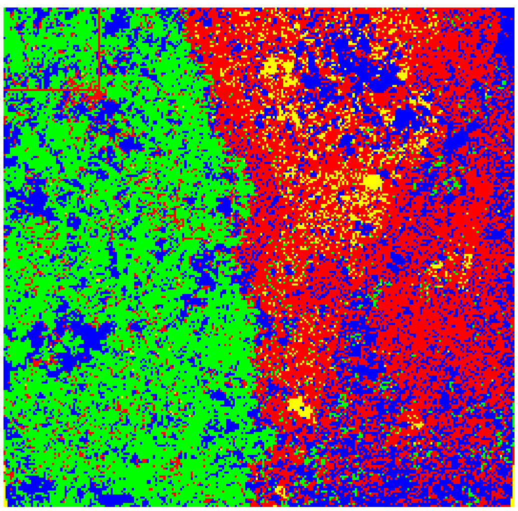
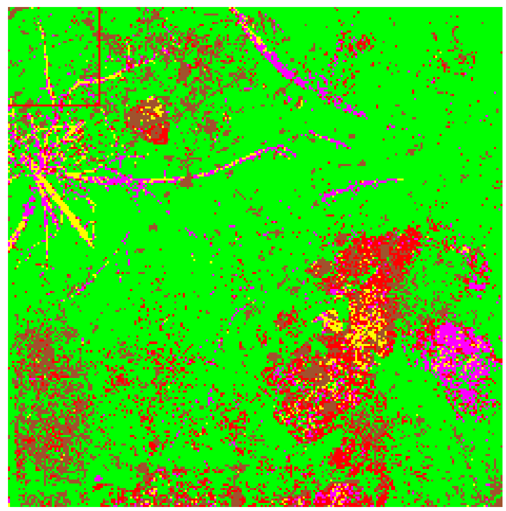
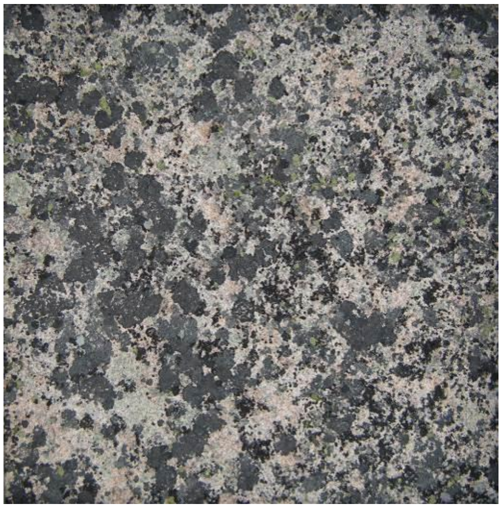
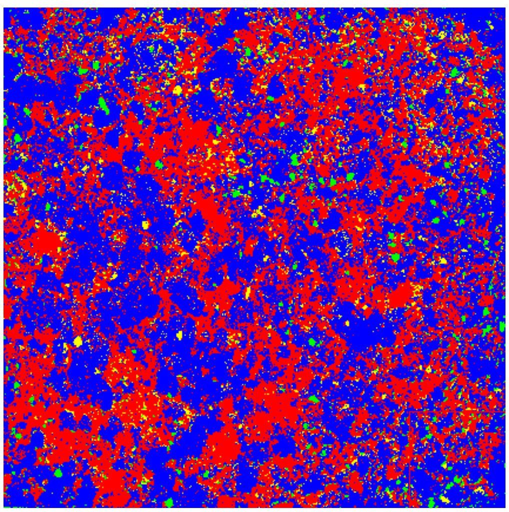
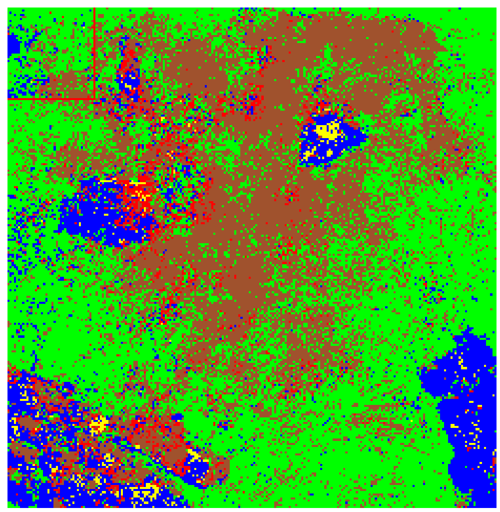
	
Quad 127	Quad 183
	
Red (light-colored lichen/veg/rock/soil) = 30.9% Blue (dark shadows/lichen/soil) = 26.8% Green (vegetation) = 30.9% Yellow (whitish lichen) = 9.8%	Red (light-colored rock & lichen) = 8.3 % Green (veg/soil) = 68% % Brown (senesced veg) = 10.6 % Yellow (whitish wood/rock) = 7.4 % Magenta (wood/rock)=5.7%

Figure 20. ENVI analyses showing selected quadrat photos and resulting image classification photos and numerical output (continued on next page).

	
Quad 190	Quad 175
	
Red (light-colored rock/lichen) = 35.6% Blue (dark lichen) = 49.3% Green (green lichen) = 4.6% Yellow (whitish lichen) = 10.5%	Red & Blue (rock/lichen) = 17.9% Green (vegetation) = 43% Brown (senesced veg/pink granite) = 30.7% Yellow (whitish lichen) = 8.3%

DISCUSSION AND MANAGEMENT OPTIONS

As noted in the Introduction, approximately 500,000 of Acadia NP visitors drive to the top of Cadillac Mountain and most of these visitors hike the paved 0.3-mile summit loop trail. Further, studies indicate that in the absence of educational signs and barriers, 74% of hikers venture off the formal paved summit trail (370,000 off-trail hikers). A study that evaluated the efficacy of interventions designed to deter off-trail hiking found no difference between signs permitting off-trail hiking on rocks (current park policy, see Figure 1), and signs asking visitors to remain only on the paved loop trail (Park *et al.* 2008). These signs reduced off-trail hiking rates to about 60% (300,000 off-trail hikers). Significantly greater efficacy was achieved by adding small symbolic "prompter" signs showing a boot print with a large red slash across it at two dozen locations where informal trails branched off the paved loop trail. This treatment reduced off-trail rates to 24.3% (121,500 off-trail hikers). Finally, adding low symbolic fencing, similar to a tall trail border of rocks, reduced the off-trail rate to 1.2% (6,000 off-trail hikers).

This current research revealed that off-trail traffic within the Cadillac study area has resulted in the creation of 323 informal trail segments that total 1.46 miles, with a mean width of 25 inches and 17,188 ft^2 of direct trampling disturbance to vegetation and soils (2.2% of the study area). Half of these trails were rated condition class 4 or 5, indicating nearly complete loss of vegetation and organic litter cover, with soil erosion evident on 24% of theses visitor-created trails. As revealed in Figure 13, these informal trails are predominantly short segments that show up in the vegetated areas surrounding the exposed bedrock. The large number and wide distribution of these trails indicates that visitors who walk off the paved trail onto bedrock surfaces, which current park policy condones, do not stop and turn around when they encounter surrounding vegetation.

Soil loss is evident in areas that have received the most intensive visitor traffic. This is of greater management concern as the summits within Acadia NP have thin lenses of soil that are critical in supporting the limited patches of vegetation. When visitor trampling removes vegetation cover, the exposed soils become vulnerable to erosion and loss by water runoff and wind. Research protocols were developed and field-tested, improved, and applied at seven summit locations. These protocols employ inexpensive lasers to establish replicable transects referenced to small drilled holes in bedrock that enable accurate measurements of soil loss as part of a monitoring program. The final protocols represent an optimal balance between management efficiency, sensitivity, accuracy, and precision.

Summit quadrat-based land cover assessments provided the most comprehensive, accurate, and sensitive means for assessing and monitoring off-trail trampling disturbance. This research applied a random stratified sampling design to place and collect photos from 239 quadrats, with non-quadrat cover assessments at an additional 67 locations. A number of different methods were employed to evaluate data from these sample points and quadrat images. Several methods provide cover estimates for various categories of land cover (e.g., different vegetation types, bedrock, exposed soil) but these did not specifically address study objectives, which are focused on documenting and monitoring the extent of off-trail trampling impacts. For example, different land-cover types do exhibit differential tolerance to recreation disturbance from trampling (Cole 1995a, 1995b). Intensive visitor traffic could replace woody vegetation and broad-leafed herbs with grasses or exposed soil, but such compositional changes are also influenced by and confounded with other ecological processes such as plant succession, short- or long-term changes in rainfall, and global climate change.

Instead, we suggest a focus on just two indicators of visual trampling disturbance: vegetation and exposed soil. Trampling disturbance on *bedrock* is difficult to discern and estimates are likely to be imprecise between different evaluators. Crustose lichen also appear to be highly tolerant of trampling disturbance and we believe there is little impact of ecological, aesthetic, or managerial relevance. In contrast, trampling to *vegetation* is generally visible, and more precise estimates of cover can be made. However, visible trampling damage to vegetation is relatively rare, only 1.8%, and this impact is dynamic and seasonal, i.e., it can vary from year to year and seasonally (monthly) depending on visitor traffic. However, vegetation trampling is a shorter-term impact that can provide an early warning to management and which is more responsive to corrective management actions.

Perhaps the best indicator is *exposed soil*, as this represents a more permanent trampling-related impact that is very discrete and clear in the quadrat photos, and which received relatively high precision between staff and the SamplePoint estimators (Table 5). Onscreen assessments of this indicator found that 6.0% of the study area has exposed soil, a surprisingly high value. Though less responsive in the short term to management actions, this indicator has high ecological, aesthetic, and managerial value. Exposed soil can be more readily lost due to wind and water erosion, it is the most long-term form of trampling impact, and it is the most visually obvious form of impact that visitors are likely to notice or view negatively. It is interesting to note that if the disturbed vegetation and exposed soil percentages are summed (7.8%) that the informal trail assessments only account for 2.2%, leaving 5.6% of trampling disturbance occurring to vegetation and soils away from informal trails. This was also an unexpectedly high value.

The necessary photographs could be obtained by returning to the sample points using GPS and the prior set of quadrat photos to reposition and retake matching digital photos, and returning to the non-photo sample points for field-based estimates. This method also yields long-term photographic documentation of groundcover changes for future reference and use. A more efficient option is to conduct assessments of visually obvious trampling damage to vegetation and soils in the field with a lightweight PVC tubing quadrat. Both options are highly efficient and yield what we believe are sufficiently accurate and precise estimates of trampling disturbance, the primary indicator of concern in this monitoring effort.

Though not done in this research study, managers could employ the SamplePoint software to assess trampled vegetation (exposed soil was assessed with this method). This would undoubtedly yield a higher degree of accuracy and precision with a very limited increase in assessment time. We see little value in assessing any additional ground cover categories for the purpose of assessing or monitoring visitor impacts, though such assessments may address other natural resource management concerns.

The VegMeasure and ENVI image analysis methods provided interesting and presumably highly precise data. However, these methods, even with guided instruction, cannot detect or isolate groundcover changes specifically attributable to visitor trampling. Accuracy is also a problem, as evidenced, for example, by the failure of the ENVY analysis to isolate exposed soil, which was confounded with light-colored lichen. Finally, we expect some differences in accuracy depending on lighting conditions, for example, differences related to shadows that would occur under variable lighting, even when photos are taken under clouds or sunscreens. The potential use of these methods would benefit from further investigation of these identified problems.

Finally, we speculate briefly on potential management responses required to substantially reduce visible trampling disturbance to off-trail vegetation and soils. Experimental trampling studies reviewed by Cole (1995a, 1995b) consistently find that plant resistance and resilience, termed "tolerance" to long-term trampling pressures, are predominantly dependent on morphological characteristics. Turf-forming graminoids (grasses/sedges) are the most tolerant, followed by matted and low-growing forbs, and less tolerant are taller broad-leafed forbs, with woody shrubs as the least tolerant growth form. In vegetation dominated by forbs and woody shrubs, groundcover is greatly reduced and visible trails can form with as little as 250 passes/year (Cole 1995a, 1995b). Thus, the prevention of visible trampling disturbance from off-trail hiking on the Cadillac summit will require extremely low off-trail hiking rates, likely in the 1-2% range. Based on the earlier research (see Literature Review section), this would require low fencing or a continuous and somewhat taller rock border or scree wall along both sides of the loop trail. In order to accommodate high levels of traffic on busy days the loop trail may also require widening. Finally, educational signing would need to revised asking visitors to remain only on the formal paved trails when on the Cadillac Mountain summit.

LITERATURE CITED

Bacon, J., J. Roche, C. Elliot, & N. Nicholas. 2006. VERP: Putting Principles into Practice in Yosemite National Park. *The George Wright Forum* 23(2): 73-83.

Bayfield, N.G. & R.J. Lloyd. 1973. An approach to assessing the impact of use on a long distance footpath - the Pennine Way. *Recreation News Supplement* 8: 11-17.

Beyer, H.L. 2007. Hawth's Analysis Tools for ArcGIS. http://www.spatialecology.com/htools.

Booth, D.T., S.E. Cox, C. Fifield, M. Phillips, & N. Williamson. 2005. Image analysis compared with other methods for measuring ground cover. *Arid Land Research & Management* 19: 91-100.

Booth, D.T., S.E. Cox, & R.D. Berryman. 2006a. Point sampling digital imagery with SamplePoint. *Environmental Monitoring & Assessment* 123: 97-108.

Booth, D.T., S.E. Cox, T.W. Meikle, & C. Fitzgerald. 2006b. The accuracy of ground-cover measurements. *Rangeland Ecology & Management* 59(2): 179-188.

Booth, D.T. & S.E. Cox. 2008. Image-based monitoring to measure ecological change in rangeland. *Frontiers in Ecology and the Environment* 6(4): 185-190.

Boucher, D., J, Aviles, R. Chepote, G.O. Domínguez, & B. Vilchez. 1991. Recovery of trailside vegetation from trampling in a tropical rain forest. *Environmental Management* 15: 257-262.

Brooks, J.J. 2003. A multi-method assessment of recreation impacts at Rocky Mountain National Park. In: Visitor Use in Wilderness Study Phase 1. Colorado State University, Fort Collins, CO, p. 49.

Cao, L., D. Stow, J. Kaiser, & L. Coulter. 2007. Monitoring cross-border trails using airborne digital multispectral imagery and interactive image analysis techniques. *Geocarto International* 22(2): 107-125.

Chase, A, D. Chase, C. Fisher, S. Leinz & J. Weishample. 2012. Geospatial revolution and remote sensing LiDAR in Mesoamerican archaeology. *PNAS* 109(32): 12916-12921.

Cole, D.N. 1983. Assessing and monitoring backcountry trail conditions. USDA Forest Service Research Paper INT-303. 10 p.

Cole, D.N. 1987. Research on soil and vegetation in wilderness: A state-of-knowledge review. In: Lucas, R.C., comp. Proceedings, National Wilderness Research Conference: Issues, State-of-Knowledge, Future Directions; Fort Collins, CO.

General Technical Report INT-220. Ogden, UT: USDA Forest Service, Intermountain Research Station: 135-177.

Cole, D.N., 1990. Trampling disturbance and recovery of cryptogamic soil crusts in Grand Canyon National Park. *Great Basin Naturalist* 50(4): 321-325.

Cole, D.N. 1995a. Disturbance of natural vegetation by camping: Experimental applications of low-level stress. *Environmental Management* 19: 405-416.

Cole, D.N. 1995b. Experimental trampling of vegetation. II. Predictors of resistance and resilience. *Journal of Applied Ecology* 32: 215-224.

Cole, D.N., A.E. Watson, T.E. Hall, & D.R. Spildie. 1997. High-use destinations in wilderness: social and biophysical impacts, visitor responses, and management options. In: Research Paper INT-496. USDA Forest Service, Rocky Mountain Research Station, Ogden, UT, p. 30.

Cole, D.N. 2004. Impacts of Hiking and Camping on Soils and Vegetation: A Review. In: Environmental Impacts of Ecotourism, pp. 41-60. R. Buckley (editor). CABI Publishing: Cambridge, MA.

Cole, D.N. & C.A. Monz. 2002. Trampling disturbance of subalpine vegetation, Wind River Mountains, Wyoming. *Arctic, Antarctic & Alpine Research* 34(4): 365–376.

Dixon, G., M. Hawes, & G. McPherson. 2004. Monitoring and modeling walking track impacts in the Tasmanian wilderness world Heritage area, Australia. *Journal of Environmental Management* 71: 305-320.

Ebersole, J.J., R.F. Bay, & D. Conlin. 2002. Restoring High-alpine Social trails on the Colorado Fourteeners. In: Perrow, M.R. & A.J. Davy, editors. Handbook of Ecological Restoration. Vol 2: Restoration in Practice. Cambridge, United Kingdom: Cambridge University Press, pp. 389–391.

Fritz, J.D. 1993. Effects of trail-induced sediment loads on Great Smoky Mountains National Park high gradient trout streams. M.S. Thesis. Cookville, TN: Tennessee Technological University.

Gawler, S. & A. Cutko. 2010. Natural Landscapes of Maine: A Guide to Natural Communities and Ecosystems. Maine Natural Areas Program. Augusta, ME.

Grabherr, G. 1982. The impact of trampling by tourists on a high altitudinal grassland in the Tyrolean Alps, Austria. *Vegetatio* 48: 209-217.

Hammitt, W.E. & D.N. Cole. 1998. Wildland Recreation: Ecology and Management (2nd Ed.). New York: John Wiley and Sons.

Hockett, K., A. Clark, Y.F. Leung, J.L. Marion & L. Park. 2010. Deterring off-trail hiking in Protected Natural Areas: Evaluating Options with Surveys and Unobtrusive Observation. Final Research Report. Virginia Tech College of Natural Resources & Environment, Blacksburg, VA.

Jacobi, C. 2011. Hiker Use of Selected Summits and Trails in Acadia National Park, 2010. Acadia National Park Resource Report 2011-12. 37pp.

Johnson, D.R., & T.C. Swearingen. 1992. The effectiveness of selected trailside sign texts in deterring off-trail hiking at paradise meadow, Mount Rainier National Park. USDA Forest Service, Pacific Northwest Research Station, Gen. Tech. Rpt. PNW-GTR.

Johnson, B., S. Bratton & I. Firth. 1987. The Feasibility of Using Brushing to Deter Visitor Use of Unofficial Trails at Craggy Gardens Blue Ridge Parkway, North Carolina. USDI National Park Service, Cooperative Studies Unit. Institute of Ecology, University of Georgia, Athens, GA.

Johnson, M.D., P. Clark, M. Louhaichi, A. Worz, S.K. Ndzieze, & D.E. Johnson. 2009. VegMeasure Z: A Software Package that Facilitates Measurement of Foliar Cover, Litter, and Bare Ground on Rangelands. Oregon State University Extension Publications. BEEF008:1-10.

Kaiser, J.V., D.A. Stow, & L. Cao. 2004. Evaluation of remote sensing techniques for mapping transborder trails. *Photogrammetric Engineering & Remote Sensing* 70(12): 1441–1447.

Kincey, M. & K. Challis. 2010. Monitoring fragile upland landscapes: The application of airborne LiDAR. *Journal for Nature Conservation* 18(2): 126–134.

Leonard, R.E. & A.M. Whitney. 1977. Trail transect: A method for documenting trail changes. USDA Forest Service, Northeastern Forest Experiment Station, Research Paper NE-389. Upper Darby, PA.

Leung, Y.F., & J. Louie. 2008. Visitor Experience and Resource Protection Data Analysis Protocol: Social Trails. North Carolina State University, Raleigh, NC, p. 17.

Leung, Y.F & J.L. Marion. 1996. Trail degradation as influenced by environmental factors: A state-of-knowledge review. *Journal of Soil and Water Conservation* 51(2): 130-136.

Leung, Y.F. & J.L. Marion. 1999a. Assessing trail conditions in protected areas: An application of a problem-assessment method in Great Smoky Mountains National Park, USA. *Environmental Conservation* 26: 270-279.

Leung, Y.F. & J.L. Marion. 1999b. The influence of sampling interval on the accuracy of trail impact assessment. *Landscape and Urban Planning* 43: 167-179.

Leung, Y.F. & J.L. Marion. 2000. Recreation impacts and management in wilderness: A state of knowledge review. USDA Forest Service Proceedings RMRS-P-15-VOL5: 23-48.

Leung, Y.F., N. Shaw, K. Johnson, & R. Duhaime. 2002. More than a database: Integrating GIS data with the Boston Harbor Islands visitor carrying capacity study. *George Wright Forum* 19(1): 69–78.

Liddle, M.J. & P. Greig-Smith. 1975. A survey of tracks and paths in a sand dune ecosystem, I. Soils. *Journal of Applied Ecology* 12: 893-908.

Lubinski, S., K. Hop, & S. Gawler. 2003. U.S. Geological Survey-National Park Service vegetation mapping program, Acadia National Park Maine. USGS, LaCrosse, WI, and Maine Natural Areas Program, Augusta, ME.

Maine Geological Survey. 2011. State of Maine, Department of Conservation Website: http://www.maine.gov/doc/nrimc/mgs/mgs.htm.

Manning, R., C. Jacobi, & J.L. Marion. 2006. Acadia National Park visitor use and impact monitoring programs for carrying capacity decision-making. *George Wright Forum* 23(2): 59–72.

Marion, J.L. 1994. An Assessment of Trail Conditions in Great Smoky Mountains National Park. Research/Resources Management Report. USDI National Park Service, Southeast Region, Atlanta, GA. 155p.

Marion, J.L. & K. Cahill. 2004. Monitoring the Resource Impacts of Visitor Use. A Protocol for the Long-term Coastal Ecosystem Monitoring Program at Cape Cod National Seashore. USDI U.S. Geological Survey, Final Research Rpt. Virginia Tech Field Station, Blacksburg, VA.

Marion, J.L. & K. Hockett. 2008. Trail and Campsite Monitoring Protocols: Zion National Park. Final Research Report. USDI U.S. Geological Survey, Virginia Tech Field Station, Blacksburg, Virginia, USA.

Marion, J.L. & Y.F. Leung. 2011. Indicators and protocols for monitoring impacts of formal and informal trails in protected areas. *Journal of Tourism & Leisure Studies* 17(2): 215-236.

Marion, J.L. & Y.F. Leung. 2001. Trail resource impacts and an examination of alternative assessment techniques. *Journal of Park and Recreation Administration* 19(1): 17-37.

Marion, J.L. & N. Olive. 2006. Assessing and Understanding Trail Degradation: Results from Big South Fork National River and Recreational Area. Research/Resources

Management Rpt. USDI National Park Service, Big South Fork National River and Recreation Area, Onieda, TN.

Marion, J.L. & J.F. Wimpey. 2011. Informal Trail Monitoring Protocols: Denali National Park and Preserve. Final Research Report. U.S. Geological Survey, Distributed by the Virginia Tech College of Natural Resources, Blacksburg, VA.

Marion, J.L., J.F. Wimpey & L.O. Park. 2011. Informal and Formal Trail Monitoring Protocols and Baseline Conditions: Acadia National Park. Final Research Report. U.S. Geological Survey, Distributed by the Virginia Tech College of Natural Resources & Environment, Blacksburg, VA. 120p.

Marion, J.L., J.F. Wimpey, & L.O. Park. 2012. The science of trail surveys: Recreation ecology provides new tools for managing wilderness trails. *Park Science* 28(3): 60-65.

Marion, J.L., Y.F. Leung, & S. Nepal. 2006. Monitoring trail conditions: New methodological considerations. *George Wright Forum* 23(2): 36-49.

Matheny, S.J. 1979. A successful campaign to reduce trail switchback shortcutting. In: Recreational Impacts on Wildlands: Conference Proceedings. USDA U.S. Forest Service, Pacific Northwest Region, Portland, OR, pp. 217-221.

National Park Service. 1997. The Visitor Experience and Resource Protection (VERP) Framework: A Handbook for Planners and Managers. USDI National Park Service, Denver Service Center, Publication No. NPS D-1215, Denver, CO.

National Park Service. 2001. Management Policies. USDI National Park Service, Washington, D.C.

National Park Service. 1992. General Management Plan, Acadia National Park, Maine. USDI National Park Service, North Atlantic Region.

National Park Service. 2009. USDI National Park Service, Public Use Statistics Office (http://www.nature.nps.gov/stats/viewReport.cfm).

National Park Service. 2011. USDI National Park Service, Public Use Statistics Office (http://www.nature.nps.gov/stats/viewReport.cfm).

Olive, N.D. & J.L. Marion. 2009. The influence of use-related, environmental and managerial factors on soil loss from recreational trails. *Journal of Environmental Management* 90(3): 1483–1493.

Park, L.O., R.E. Manning, J.L. Marion, S.R. Lawson, C. Jacobi. 2008. Managing visitor impacts in parks: A multi-method study of the effectiveness of alternative management practices. *Journal of Parks and Recreation Administration* 26(1): 97-121.

Park, L.O., J.L. Marion, J.F. Wimpey, & C. Jacobi. In Press. Efficacy of education and site management in reducing off-trail travel in a fragile biotic community, Acadia National Park. *Journal of Parks & Recreation Administration*

Park Studies Unit. 2009. Acadia National Park Visitor Study. USDI National Park Service, Social Science Program, Visitor Services Project. Report 221.

Pickering, C.M. & R.C. Buckley. 2003. Swarming to the summit: Managing tourists at Mt Kosciuszko, Australia. *Mountain Research and Development* 23(3): 230–233.

Pickering, C.M. & A. Mount. 2010. Do tourists disperse weed seed? A global review of unintentional human-mediated terrestrial seed dispersal on clothing, vehicles and horses. *Journal of Sustainable Tourism* 18(2): 239–256.

Rochefort, R.M. & D.D. Swinney. 2000. Human Impact Surveys in Mount Rainier National Park: Past, Present, and Future. In: Cole, D.N.; McCool, S.F.; Borrie, W.T.; O'Loughlin,J., compilers. Wilderness Science in a Time of Change Conference—Vol. 5: Wilderness Ecosystems, Threats, and Management; 1999 May 23–27; Missoula, MT. Proceedings RMRS-P-15-VOL-5. USDA Forest Service, Rocky Mountain Research Station, Ogden, UT.

Roggenbuck, J.W. 1992. Use of Persuasion to Reduce Resource Impacts and Visitor Conflicts. In: Manfredo, M.J. (Ed.), Influencing Human Behavior. Sagamore Publishing Incorporated, Champaign, IL, p. 371.

Roovers, P., B. Bossuyt, H. Gulnick, & M. Hermy. 2005. Vegetation recovery on closed paths in temperate deciduous forests. *Journal of Environmental Management* 74: 273-281.

Seefeldt, S.S. & T.D. Booth. 2006. Measuring plant cover in Sagebrush Steppe Rangelands: A comparison of methods. *Environmental Management* 37(5): 703-711.

Stuart Clement Solutions. 1010. Gap Creek Circuit Mountain Bike Trail: Long Term Environmental Use Impacts. Gap Creek Trails Alliance. Adelaide, South Australia.

Sutter, R.D., S.E. Benjamin, N. Murdock, B. Teague. 1993. Monitoring the effectiveness of a boardwalk at protecting a low heath bald in the southern Appalachians. *Natural Areas Journal* 13(4): 250-255.

Turner, R. & W. LaPage. 2002. Visitor behavior and resource impacts at Cadillac Mountain, Acadia National Park. In: Todd, S., comp., ed. 2002. Proceedings of the 2001 Northeastern Recreation Research Symp. Gen. Tech. Rpt. NE-289, USDA Forest Service, Northeastern Research Station, Newtown Square, PA. pp. 175-179.

Tyser, R.W. & C.A. Worley. 1992. Alien flora in grasslands adjacent to road and trail corridors in Glacier National Park, Montana (U.S.A.). *Conservation Biology* 6(2): 253-262.

Wessels, T. 2001. The Granite Landscape: A Natural History of America's Mountain Domes, from Acadia to Yosemite. The Countryman Press. Woodstack, VT. 203 pp.

Willard, B.E., D.J. Cooper, & B.C. Forbes. 2007. Natural regeneration of alpine tundra vegetation after human trampling: A 42-year data set from Rocky Mountain National Park, Colorado, USA. *Arctic, Antarctic, and Alpine Research* 39(1): 177–183.

Wing, M. & B. Shelby. 1999. Using GIS to integrate information on forest recreation. *Journal of Forestry* 97(1): 12-16.

Wimpey, J.F. & J.L. Marion. 2011a. A spatial exploration of informal trail networks within Great Falls Park, VA. *Journal of Environmental Management* 92: 1012-1022.

Wimpey, J.F. & J.L. Marion. 2011b. Formal and informal trail monitoring protocols and baseline conditions: Great Falls Park and Potomac Gorge. Final Research Report. USDI U.S. Geological Survey, Distributed by the Virginia Tech College of Natural Resources & Environment, Blacksburg, VA.

Witztum, E.R. & D.A. Stow. 2004. Analyzing direct impacts of recreation activity on coastal sage scrub habitat with very high resolution multi-spectral imagery. *International Journal of Remote Sensing* 25(17): 3477-3496.

Wolper, J., S. Mohamed, S. Burt, & R. Young. 1994. Multisensor GPS-based recreational trail mapping. In Proceedings of ION GPS 1994 (VOL 7/V1) Institute of Navigation, Alexandria, VA. pp. 237-244.

Wood, K.T., S.R. Lawson, & J.L. Marion. 2006. Assessing recreation impacts to cliffs in Shenandoah national park: integrating visitor observation with trail and recreation site measurements. *Journal of Park & Recreation Administration* 24(4): 86-110.

APPENDIX 1: CENSUS TRAIL MAPPING SURVEY

Objectives

This survey documents the location, spatial distribution, and lineal extent of all informal trails within selected search polygons. Optional procedures are included for assessing trail conditions if needed. When reapplied over time, census mapping survey procedures allow managers to accurately track and characterize changes in the number, spatial distribution, and length of informal trails, and optionally, changes in their condition. Data can also be used to help decide which informal trails should be closed and to evaluate the success of management efforts to close selected trails or prevent the creation of new trails.

Guidance

Census mapping areas (CMAs) are identified by park staff based on management and planning information needs. All informal trails within each CMA are inventoried as line features, with point features recorded at all trail/road intersections to aid GIS editing. Optional assessments of use type, trail width, maximum incision, vegetation cover, and bare soil can be made at locations where informal trails intersect a GIS grid (e.g., 25 or 50-meter grid) superimposed over the CMA and downloaded for viewing during survey work on a GPS unit. See Marion & Wimpey (2011) for additional information about these protocols and examples of data derived from their application.

Methods

Materials

- Field manual, data/photos from prior surveys, paper data forms and pencil for backup.
- Trimble GPS, charged battery(s), antenna, stylus, appropriate data dictionary, and CMA polygons.
- Compass
- Optional: GIS grid vector file downloaded to GPS unit.
- Telescopic antenna or presentation pointer (extending to 4 ft).
- Tape measure, 6 ft.
- Geotag-enabled digital camera that links with Trimble GPS position data (preferred). Option: use a standard digital camera, set it's time date/time to match the Trimble unit, and use a software program that matches date/time stamps to record location data to the photo file (geotagging).
- Logbook

Field Procedures

Begin by exploring the previously defined CMA area to get a sense of its size and location, and presence of informal trails. Reassess the boundaries of the search polygon developed by the roundtable process and record point and/or polygon features and descriptive notes if needed to document alterations based on local topography, existing trails, or possible additional areas where trails could develop.

Open TerraSync on the GPS and select the Data screen to create a new rover file. Select the CMA data dictionary from the pick list.

Select the Map screen and open the Layers dialog. Select "Background Files...," locate the appropriate CMA mapping area polygon layer and designate it as the background layer. Conduct all mapping efforts in the field within this polygon, making note for later revision if the boundary polygon needs to be modified based on the field visit.

Select the Setup screen, and open the Logging Settings dialog. Ensure logging intervals for all features in the data dictionary are set to 1 second and are based on time, not distance. Logging velocity is unnecessary, set H-Star logging to Auto, and set Allow Position Update to Confirm.

Beginning in one corner of the CMA polygon, record each informal trail segment as an "IT_Segment." Note that trail segments must be at least 10 ft in length, and that mapping should cease for gaps of more than 10 ft. If the CMA has a dense network of interconnected trails if may be helpful to carry some flagging or wire pine flags to place at intersections to denote which trails have been mapped.

Ensure that the GPS records points as you move along each trail segment, every time the unit beeps and updates the point count, it has placed a node along the line you are collecting with the GPS. You are collecting a trail and need to make sure you collect points along it that adequately capture the location and shape of the trail. Watch the background file showing the CMA boundaries and stop assessing all trails at the study area boundary. To promote efficiency in post-hoc data cleanup, pause data collection in the Data or Map screens when standing still. This prevents the unit from collecting a cloud of points when it is not moving.

At intersections with other informal trails, nest an "IT_Junction" to improve mapping accuracy in GIS data editing. Use the Options menu in the Data screen and select "Nest," then select the "IT_Junction" point feature. While the point is averaging positions, record the number of trail segments meeting at this junction. For example, a "T-intersection" has three connecting segments. Once the minimum number of positions have been collected for the "IT_Junction", close the feature, and continue mapping by unpausing/resuming data collection on the GPS.

Resource Condition Photos: Periodically take digital photos of representative trails that are being mapped. Record "CMA Photo Point" at each point, attribute with camera photo numbers, and azimuth of image. These photos can be examined to document the general conditions and attributes of the mapped trails. Photos could also be replicated during subsequent surveys for comparing changes in resource conditions (e.g., width, depth, substrates, muddiness).

Continue mapping until all informal trails within the CMA boundaries have been walked and recorded.

- Resource Condition Comments: At the conclusion of mapping work for each separate area, prepare a written summary that qualitatively describes the area and resource conditions along the trails. Focus your comments on the relative proportion of trails that are obvious and distinct vs. faint and inconsistent. Also note the number of occurrences of "problem" sections due to excessive muddiness or rutting that may contribute to trail proliferation and tread widening.

Optional Grid-Based Trail Condition Assessment Protocols

The primary focus of census mapping is to efficiently document the number, lineal extent and spatial distribution of informal trails. Resource condition impacts such as muddiness and soil loss can cause the proliferation of additional parallel trails that census mapping can document. However, sometimes it may be beneficial to also have qualitative or quantitative data on the condition of the mapped informal trails. Research and trials by independent trail surveyors conducted at Denali National Park revealed that field staff moving along the trails frequently differed in their subjective walking assessments of attributes such as condition class and trail width. Adding condition assessment indicators that are continuously assessed and altered for different segments of the mapped trails also increases the complexity of the mapping process and slows it down.

Two efficient options for characterizing the resource condition of informal trails include taking representative resource condition photos of informal trails during the census mapping fieldwork and writing a resource condition summary for each area mapped. Both these options are included in the standard procedures.

More comprehensive and accurate quantitative data on the resource conditions of informal trail networks can be collected by adding an optional grid-based trail condition assessment described here. Better data can be collected when assessments are performed at specific sample points rather than for trail segments. Point data can be averaged to obtain a more accurate and robust estimate of informal trail conditions for various areas.

A recommended method for efficiently sampling informal trail networks during or after census mapping is to create a grid superimposed on the CMA and viewable on the GPS. The size of the grid spacing (e.g., 10m) determines the number of sample points that are collected and could vary by CMA based on trail density. Survey staff stop at each informal trail/grid intersection and assess trail conditions for any subset of the indicators described below. To improve efficiency, staff should assess trails only the first time they cross a grid line segment i.e., don't assess a second crossing within the same grid cell.

Optional Condition Assessment Protocols

1) *Trail Width (TW):* Measure the trail width between the outer trail boundaries. These boundaries are defined as visually obvious trampling-related changes in ground vegetation height (trampled vs. untrampled), cover, composition (e.g., grass, forb, lichen), or, when vegetation cover is reduced or absent, changes in organic litter (intact vs. pulverized) (see photo illustrations in Figure 2). The objective is to define the trail tread that receives about 95% of the traffic, selecting the most visually obvious outer boundary that can be consistently identified by you and future trail surveyors. Measure and record the tread width to the nearest inch.

2) *Total Incision (TI):* Extend a telescoping antenna or shock-corded tent pole section across the trail and beyond trail boundaries so that it rests on what you consider to be the pre-trail surface of the lowermost ground vegetation layer (i.e., on top of the moss/lichen mat and/or at the base of grass clumps and forbs). Use a tape measure to obtain a maximum value (nearest ¼ inch: 0, .25, .5, .75) from the bottom of the pole to the lowermost point on the trail tread beneath the pole (support it in the middle if it bends downward on wider trails). Subtract soil incision (next indicator) from this measure to yield a measure reflecting trampling-related compaction or loss of the vegetation mat.

3) *Soil Incision (SI):* Same procedures as above, but now align the extension pointer at the trail boundary with the interface between the upper soil surface and lower vegetation mat. Note that this interface may be below the tread, in which case record a value of 0 for this indicator. If soil loss has occurred, use a tape measure to obtain a maximum value (nearest ¼ inch) from the bottom of the pointer to the lowermost point on the trail tread. This measure primarily reflects the trampling-related compaction or loss of the soil. Arctic Refuge: substitute a Yes/No response for this measure based on whether soil loss has occurred.

4) *Vegetation Cover On-Trail (VO):* Imagine a 1 ft wide belt transect centered on the pole extending *between* the trail boundaries perpendicular to the trail. Within this band estimate the percentage of *live* vegetative ground cover < 1 ft tall (including herbs, grasses, low shrubs, live mosses, lichens (all colors), and any largely intact cryptogrammic crusts) rooted within the band using the coded categories listed below (see Figure 2). For this and the following indicator, it is helpful to narrow your decision to two categories and concentrate on the boundary value that separates them. For example, if the vegetation cover is either category 6-25% or 26-50%, you can simplify your decision by focusing on whether vegetative cover is greater than 25%. Alternately, consider that analyses will use the midpoint values for these categories so it may be helpful to base your decision on which midpoint value is most representative of the trail tread cover. Cover categories:

   0-5% (1=2.5), 6-25% (2=15.5), 26-50% (3=38), 51-75% (4=63), 76-95% (5=85.5), 96-100% (6=98)

5) *Vegetative Ground Cover Off-Trail (VF):* Assess vegetation cover in an adjacent, untrampled off-trail location several feet beyond trail boundaries. The intent is to locate a "control" area that depicts what the vegetation cover on the trail tread would resemble had it never been trampled. Select a control that has the same proportion and size of rocks as the tread quadrat. 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 trail route with the least amount of vegetation. Note that if some of the trail substrates would likely be barren due to exposed rock, then the control substrates or control vegetation estimates must reflect that.

6) *Bare Soil On-Trail (BO):* As in #5 above, but estimate bare/exposed soil cover, defined as rocks, gravel, roots, and exposed soil of all types, including organic soils with pulverized organic litter (see Figure 2). Total cover for each band transect should

approximately equal the sum of your mid-point estimates for #5, #7, and organic litter cover.

7) *Bare Soil Off-Trail (BF):* As above, with the cover estimate of bare soil (not organic litter) made in the same off-trail location used for the vegetation assessment.

8) *Tread Problems (TP):* Record as 1) None, 2) Mud <1", 3) Mud 1-3", 4) Mud >4", 5) Active Erosion Occurring.

Figure 1. Reference photos illustrating faint and/or discontinuous informal trails defined by the effects of trampling disturbance, including: 1) reduction in woody vegetation, 2)

flattening, abrasion, or reduction in herb and grass cover, 3) compressed or reduced moss

and lichen cover, and/or 4) sorting or disturbance of rocks.

Figure 2. Representative photos illustrating the placement of telescopic antenna or shock-corded tent pole extending beyond trail borders and from which is measured veg/soil maximum incision to deepest spot along the tread. Trail width is assessed along the antenna between the blue lines. Vegetation and bare

soil (see definitions and cover categories above) are assessed for the trail in a band 1 ft wide centered on the pointer. See reference assessments included in yellow on the photos. Off-site vegetation and bare soil values are assessed in representative undisturbed areas several feet beyond the ends of the pointer.

Data Dictionaries

Census Mapping.ddf

Pre-fieldwork Setup Tasks

1. Load necessary data dictionary(s) sample region and background data sets onto the Trimble GPS(s).
2. Ensure that batteries are charged and ancillary equipment is ready for use:
    a. External batteries,
    b. Antennas and leads,
    c. Backpack antenna mount,
    d. Clinometer, digital camera, and measurement tools as required by sampling protocol to be implemented,
    e. Logbook and forms as needed.
3. Create and print schematic/directions to get to sampling area (if needed).

Field Tasks

1. Navigate to the sampling location(s).
2. Implement required sampling protocols(s).
3. Fill in logbook indicating work completed, dates, and field staff names.
4. Return equipment to office with completed logbook and written summaries.

Data Post-Processing Tasks

This guidance provides an outline for post-processing GPS data and implementing an organized and easily transferable/updateable spatial database. Post-processing and creation/integration of spatial datasets should be done by a single person, preferably by a GIS staff member. When transferring the data to the GIS staff, field staff should include a brief narrative describing the GPS data. This narrative should include:

- Date(s) of collection
- Field staff names and contact information
- Type of survey(s) collected
- Area of collection
- Additional comments or notes that may be pertinent

Suggested Protocols

Use Trimble's Pathfinder Office software to post-process data (differentially correct, edit and convert to ESRI shapefiles). Staff should be careful to not create redundant datasets, and to name files using a system that allows for integration into existing park datasets.

- Always work in one Pathfinder Office Project (do not create a new project each time you correct data)
- Download data from GPS devices.
- Verify the contents vs. logbook and note any discrepancies (contact field staff to resolve).
- Differentially correct GPS data.
- Name Files appropriately and/or maintain a spreadsheet with a key to interpret default GPS rover/pathfinder file names.
- Export data to ESRI shapefile using a template that creates shapefiles with desired attributes and coordinate system. Clean up and recode attribute data, enter paper form data as needed.
- Integrate Shapefiles into existing ArcMAP Spatial Databases
- Use standardized file naming conventions with file storage in separate project folders and maintain appropriate back-up and archiving of datasets.

Monitoring Tasks

1. Create summary data (maps, tables, photo compilations).
2. Prepare comparisons between areas of interest and across time
    a. Calculate indicator attributes of interest,
    b. Prepare maps to facilitate visual comparison of spatial data.
3. Update monitoring/sampling plans:
    a. Based on datasets coming in and comparisons to other times and/or locations,
    b. Based on input from field staff, rangers, etc.

APPENDIX 2: MONITORING PROTOCOLS FOR ASSESSING SOIL LOSS

(version 11/28/08)

This protocol describes a method for assessing soil loss or deposition on trails or recreation sites. The method uses a laser beam and to two permanent reference points. The profile of the ground surface is measured along a transect between the two reference points, at two or more times. The difference between the profiles at the two times represents soil erosion or deposition. The procedure was developed to assess soil loss on the summits of northeastern mountains but is applicable to other locations such as campsites or archaeological sites. Generally the reference points would be on bedrock or large immovable boulders but 3 ft sections of steel rebar hammered into the ground could substitute in areas lacking rock. The rock (or rebar) serves as the elevation datum from which the ground profiles are measured.

Equipment Needed

Laser level – An automatic pendulum level is recommended. The laser should project a dot (not a chalk line) and include a ¼-20 thread tripod mounting base. Automatic level lasers include the Pacific Laser System PLS3 (Figure 2) and the CST/Berger 58-MP3 (Figure 3). Also acceptable are low cost, rugged, manual adjust, bubble levels such as the Stanley SP2 Torpedo Laser Level (Figure 1).

Spare batteries for laser

Measuring stick with target slider (to measure distance from laser line to the ground surface), 3/8 in dia. x 65 cm length wooden dowel and a ¾ in square x 15/8 long block with a 3/8in dia. hole drilled in the center (Figures 1 & 3)

Small sand bag, tripod head mounted on a board and/or short tripod (to support the laser)

Ruler, 65 cm length (to measure slider position)

Storage tube for ruler and measuring stick (to prevent breakage)

Tape measure, metric, ≥10 m (semi-rigid metal type, not the flexible cloth type)

Sand bags to support A and B ends of tape measure

C-clamp to support A (zero) end of tape measure

Hook attachment for A end of tape measure (to hook into drill hole at ref. point A)

Tape support stands to hold tape measure blade along the tape line, three to five are needed (made from 12 gage copper electric wire twisted together, see Figures 1, 2 & 3

Plumb bob with line (≥ 4oz, with ~90cm string)

Rechargeable drill with spare batteries and charger

3/16 inch diameter diamond drill bit (for use on granite rock), spare bits

Clipboard, pencils, sharpie marker

Field forms (some on waterproof paper) and this manual

GPS (recommended with differential correction capability), spare batteries and/or charger

Compass, not corrected for declination (peephole type suggested)

Clinometer, to measure landform slope (type built into compass OK)

Digital camera, w/storage card and fresh/spare batteries

Rebar and sledge hammer (if needed)

String, 10m length (to test out orientation of “profile reference line”)

Pin flags and/or flagging (to mark bare spots)

Safety Considerations

Be careful not to shine or reflect the laser into anyone's eyes. Do not stare at or intercept the laser beam with your eyes when measuring. These are class II or III lasers that rely on the human blink response to prevent burning your retina. The measuring stick and slider have a dull surface which is less likely to reflect the laser beam into your eyes than measuring directly with a ruler. With the measuring stick and slider you make the reading with the stick removed from the laser beam.

Select Study Sites

A randomly selected sample of potential locations where permanent transects will be established is necessary to provide the ability to generalize measurements of soil loss beyond the locations that are assessed. Conduct a census of the study area to identify all locations where substantial soil exposure and the potential for soil loss are occurring. In our summit study we used $1m^2$ as the minimum area of exposed soil to qualify for inclusion in the census. At each qualifying location, the area of exposed soil (defined in Marion 1991, pg 45) will be assessed and recorded using the rapid Geometric Figure Method (see Marion 1991, pg 49). Use a GPS to record a point feature at the center of each qualifying location. Record the bare soil area on the attached field form (Erosion measurement - bare soil summary) and as a comment in the GPS point feature file.

Randomly select the desired number of exposed soil locations for profile measurement. At each selected location examine the site to determine if a line transect can be permanently referenced to bedrock, large immovable boulders, or embedded rebar at two locations on opposite sides of the soil exposure (see Figure 1, reference points A and B). Try to select these permanent reference points along a transect that maximizes the lineal distance of exposed soil but not exceeding a manageable limit of around 6 meters. For ease of measurement, attempt to position the laser beam less than 65 cm above the ground surface. If a selected location cannot be assessed as indicated then randomly select an additional location (be sure to consider alternate orientations of the transect, e.g. closer, reference points before abandoning a randomly selected location).

General description of measurement procedure

At each selected location, begin by locating the two permanent reference points, points A and B (Figure 1). A string can be run between potential A and B points to evaluate the transect location. Select a transect alignment that captures one or two larger patches of exposed soil and that lack, to the extent possible, movable rocks. Select the reference points on bedrock close to where the exposed soil begins and that provide an adequate space behind location A for the laser to be placed. Do a rough check to insure all subsequent measurements can be made before permanently marking A and B. Position A and B at local "high spots" to minimize their filling with debris.

Drill 3/16 dia. x 3/8 inch deep holes at reference points A and B. For granite rock use a diamond drill bit and dribble water to cool the bit while applying less than 20lb pressure, with a 400rpm drill speed. For best drill life, the bit should not get more than warm to the touch when drilling.

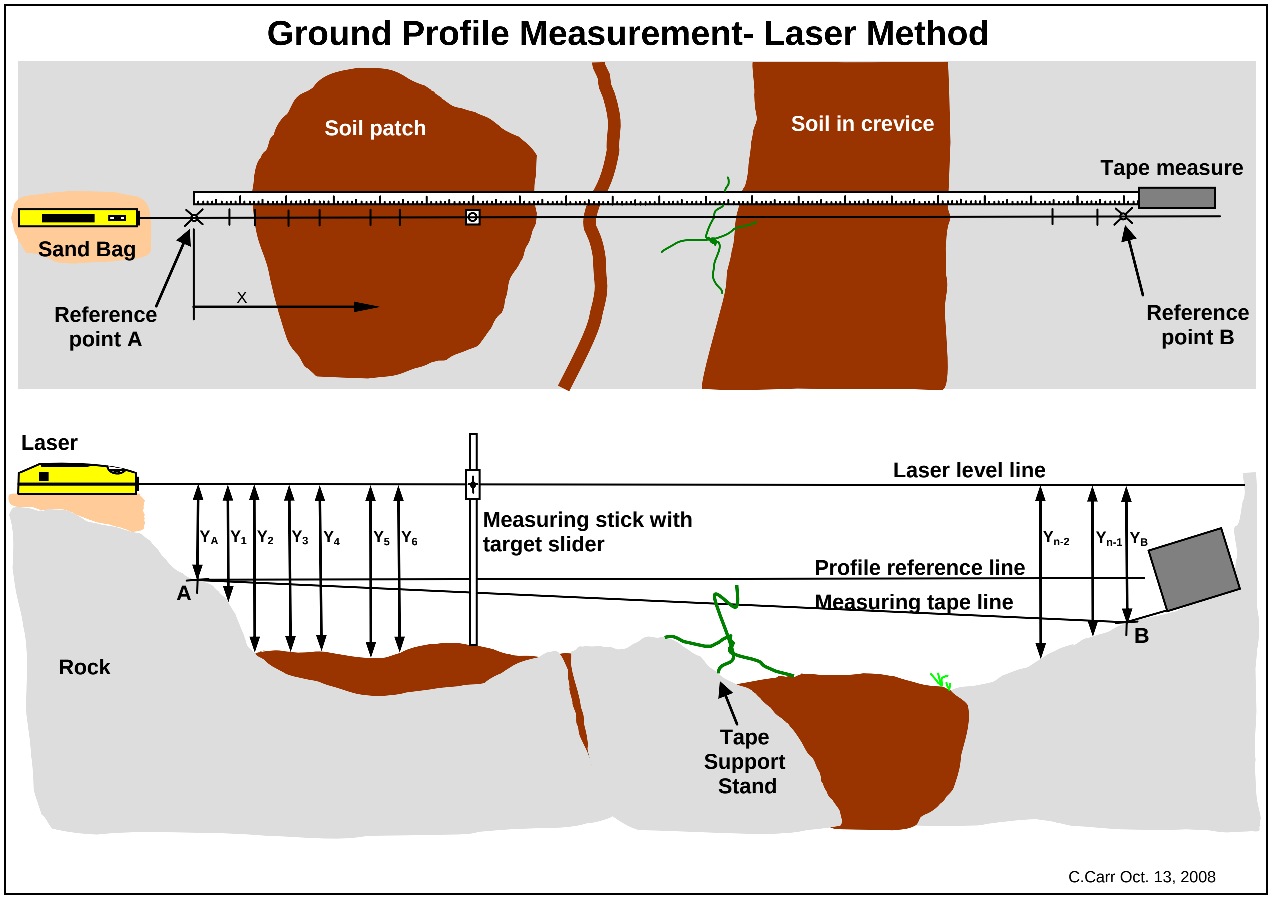


Figure 1. Ground profile measurement using a laser line referenced to fixed points A and B.

Figure 2. Photo merge of ground profile transect showing laser, tape measure and support stands.

Use a plumb bob to orient the laser beam directly above the drill holes at points A and B. A sand bag or small tripod is used to support the laser (Figure 1 & 3). Insure the laser is level (bubble centered on manual laser level, OK light on automatic level laser) and solidly positioned so wind or bumping the tape measure will not shift the laser. Measure from points A and B to the center of the laser beam and record these on the attached field form (Erosion measurement - ground profile transect).

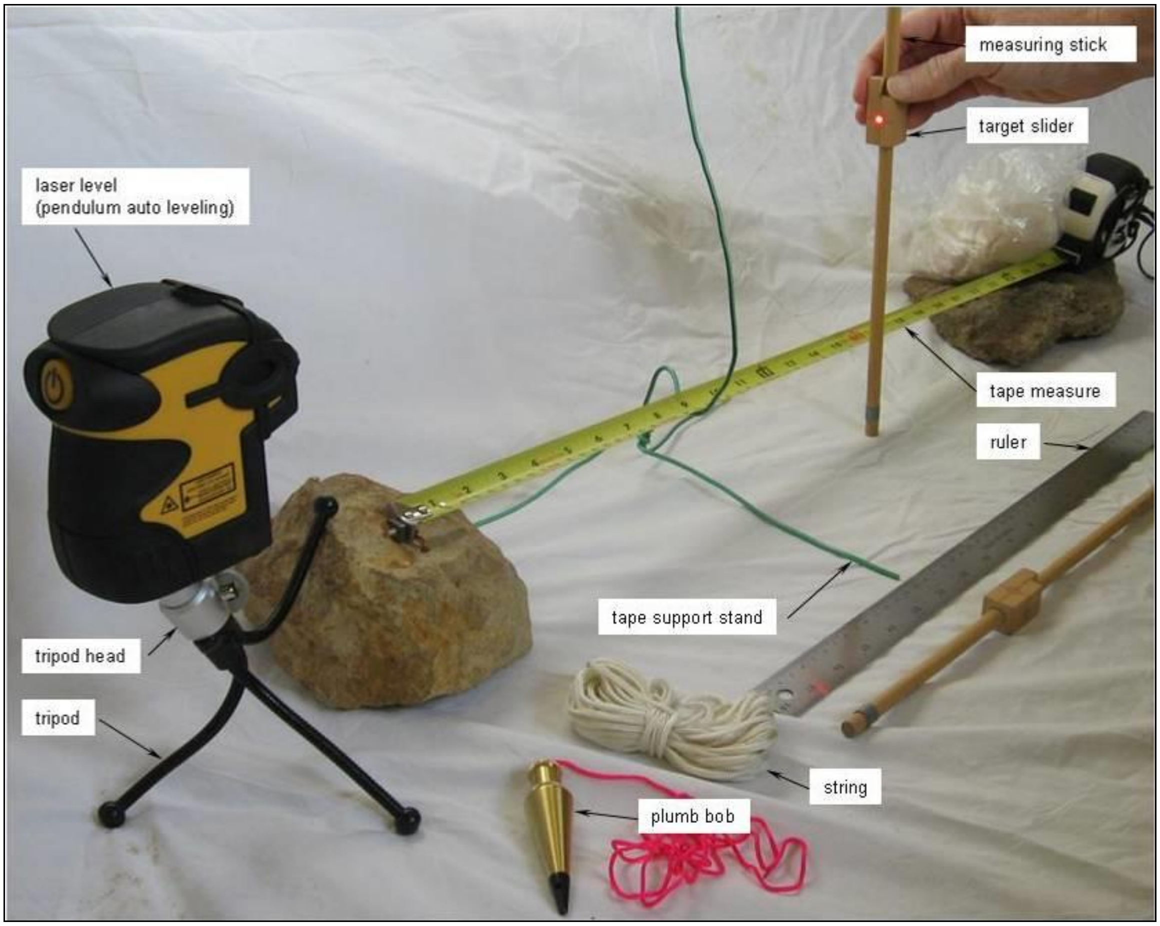


Figure 3. Equipment for ground profile measurement. CST/Berger 58-MP3 laser level is shown. Note pinch grip on target slider, laser dot on target slider cross hairs, and hook on zero end of tape measure.

Record the transect location by obtaining an averaged GPS point at reference point A and at reference point B, (differentially correct the positions with post processing to improve accuracy). Take a photo of the general area showing the transect A and B points with the photo orientated perpendicular to the line (A to the left if possible) with the laser and tape measure in the photo (see Acadia CD for example photos). Next take a series of overlapping vertical photos of the transect (for later "stitching") with the laser and tape measure in the photo but with all other gear, backpacks, etc. removed. The vertical photos should be taken from approximately the same height above the tape measure in each case (this will make the merge easier). Try for about 30% overlap in the photos. This photo sequence can be stitched together, using commonly available digital photo software, to show the transect in one photo (Figure 2).

Finally take close-up photos of Point A and B from a distance of about 2m with a pencil in the reference holes—with the laser and tape measure removed from the photo. Use a clinometer on a clipboard to assess the degree of slope from the A and B reference points, and a compass to assess the azimuth of the transect line. Label and archive the GPS points and photos in a folder with the data sheets and graphs.

Making the X and Y measurements

Support the tape measure between points A and B using the tape support stands, the "measuring tape line" in Figure 1. Beginning at point A, record a vertical "Y_i" measurement that is configured to be perpendicular to the laser line (e.g., a plumb bob measure) as shown in Figure 1. Record values in centimeters. Position yourself so the laser (and reference point A) are to the left—the measurements will then run in the conventional left to right direction. Record this measure to the nearest 0.1 cm but note that the objective is to achieve measurements in the ±0.3 cm (±1/8 in) range. Record the horizontal "X_0" distance measure along the profile reference line as 0. Continue along the tape to point B, measuring the vertical "Y_i" distance from the middle of the laser line to the ground surface.

Measurements should be frequent enough to map the profile of the ground surface along the transect and to show the transitions between the various substrates (e.g. from rock to organic soil, back to rock). When the profile is relatively flat the measurement points can be stretched out in the X-direction (but not to exceed 20cm apart). At steep changes in elevation, e.g. at the edge of a badly eroded vegetation patch, measurements should be made just before the change and just after the change. Include measurements, paired (X_i, Y_i) readings, as needed to document the beginning and end of each exposed soil patch encountered along the transect and to record any major discontinuities in the profile. When in doubt, you should record measurements at more rather than fewer positions. Recording both the soil and rock profile is important because the amount of soil deposition can only be calculated if the initial rock profile is known.

When making the vertical "Y_i" measures - move aside any easily movable rocks along the transect line, measure to the ground surface, and replace the rocks as you found them. The measuring stick with slider is used to insure a consistent "footprint" of the stick against the ground. Rest the bottom end of the measuring stick on top of the ground surface (rock, gravel, organic soil), but push through any vegetation. Note the substrate type that you are measuring to with the following codes on the field form: Rock immovable (RI), Rock movable (RM), Vegetation (V), Litter (L), and Organic Soil (OS), gravel (G). If water is present, measure through the water to the ground surface and record that surface as the substrate.

The "Y_i" measurements are taken from the horizontal "laser level line" which runs above reference points A and B. On the other hand, the "X_i" dimensions are taken along the sloping "measuring tape line" which runs between reference points A and B. The Y_A and

Y_B measurements will be used to relate measurements made at two different times and to relate the "laser level line" and the "profile reference line". (In land surveying terms, the "laser level line" is known as "height of instrument," HI).

Be careful to not disturb the laser during measurements or you may have to remake the measurements. When done taking all transect measures, re-measure the vertical distances from the center of the laser line to points A and B and ensure they match with the initial measures within 0.3 cm.

Step-by-step setup and measurement procedure

1) Select transect general location
2) Use a string stretched between possible A and B reference points to finalize A and B locations.
3) Drill 3/16 dia. x 3/8 inch deep holes at reference points A and B.
4) Position the laser on a sandbag or tripod, behind A, to shoot over reference points A and B.
5) Insure the laser is level
6) Position the tape measure to start at reference point A and run along the "profile reference line" to reference point B. Position the tape just to one side of the laser line. The zero end of the tape can be held in position with a sand bag placed on a c)clamp or with a hook, in the drill hole, on the end of the tape.
7) Bend and position the tape support stands to hold the tape measure straight, without kinks. For a ¾ inch wide tape measure the stands can be positioned about 4 feet apart.
8) Recheck that the laser line is over A and B and is level.
9) Make the X and Y measurements and enter in the field form.
10) Confirm that final Y_A and Y_B are within tolerance. If the measurements are not within tolerance recheck the laser level and position and repeat the measurements.
11) With laser and tape measure in place take the overall and vertical stitch photographs.
12) With all equipment removed, take close-up photographs of reference points A and B. Have someone hold a pencil point in the reference holes for the photographs. Try for a distinctive background in the photo to help the next person relocate your reference points.
13) Use the GPS to record, with point averaging, the positions of A and B.
14) Pack up everything and move to the next transect.

Initial Data Analysis

Enter data in Excel spreadsheets. Make graphs (Figure 4). Put photos in folders by transect, assemble photostitch (Figure 2).

<u>Computations</u>

The (X_i, Y_i) readings will be graphed to show the ground profile and substrate (rock, gravel, soil, etc.). The measures you take from the laser line to immovable rock at reference points A and B will be used in the future to ensure that computations can account and remove differences in CSA measures attributed to setting up the laser line higher or lower than it was in the baseline measurement or from differences in laser level. Measures from the laser line to other immovable rock will be used to check for consistency of measurement. The plotting and calculations will generally follow Cole (1983).

Error! Objects cannot be created from editing field codes.

Figure 4. Ground profile plots at different times (not corrected for level and HI difference)

Remeasurements

Relocate the A and B reference points for each transect and reestablish the laser line. The laser line does not have to be established at the same height above the ground as in the initial measurements. The difference in laser line heights, the before and after Y_a and Y_b measurements, will be transposed to the common position, the "profile reference line." Replicate all other procedures—measuring the Y-dimension at all the original X-positions. Add X-positions as needed to characterize the new profile.

Quality Control

The manufacturers of automatic level lasers recommend periodic checks of the laser calibration and accuracy. These checks should be done before and after each field trip. The calibration check procedures are in the laser instruction manual or in land survey text books.

The measurement team, or teams, should set up a transect at a trial location, make all the measurements and take apart the whole laser system. The team should then return and use the re-measurement method to measure again. If the profile is not within 0.3 cm of initial measures then the procedure should be reviewed and the technique refined.

Erosion Measurement - Bare Soil Summary

I. Census of bare soil sites

Area name:
Inventoried by:
Date: Time:
Description:

Item #	Waypoint #	Bare soil area (m^2)	Comments
1			
2			
3			
4			

5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
19			
20			
21			
22			
23			
24			
25			

Circle areas selected for transect measurements.

Erosion Measurement - Ground Profile Transect

I. General

Area and transect name:

Inventoried by: Date: Start time: End time:

Laser make and model:

Transect Length (cm): Transect Compass bearing (A to B, ° mag):

Fall line slope at transect (°): Fall Line Compass bearing (looking down slope, ° mag):

GPS coordinates or waypoint number reference points A: B:

Transect description:

II: Initial-measure Y_A and Y_B (cm) Y_A = Y_B =

III. Profile measurement

No.	X_i (cm)	Y_i (cm)	Substrate
0	0		RI
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			

No.	X_i (cm)	Y_i (cm)	Substrate
20			
21			
22			
23			
24			
25			
26			
27			
28			
29			
30			
31			
32			
33			
34			
35			
36			
37			
38			
39			

Substrates: Rock immovable (RI), Rock movable (RM), Vegetation (V), Litter (L), Organic Soil (OS), Gravel (G).

IV: Re-measure Y_A and Y_B (cm) Y_A = Y_B = (<0.3cm delta?)

V. Photographs

description	**look direction**	**photo #(s)**	**comments**
overall perpendicular to transect			w/ gear
vertical photo stitch of transect	vertical		w/ gear
reference point A from ~2m			w/o gear
reference point B from ~2m			w/o gear

References

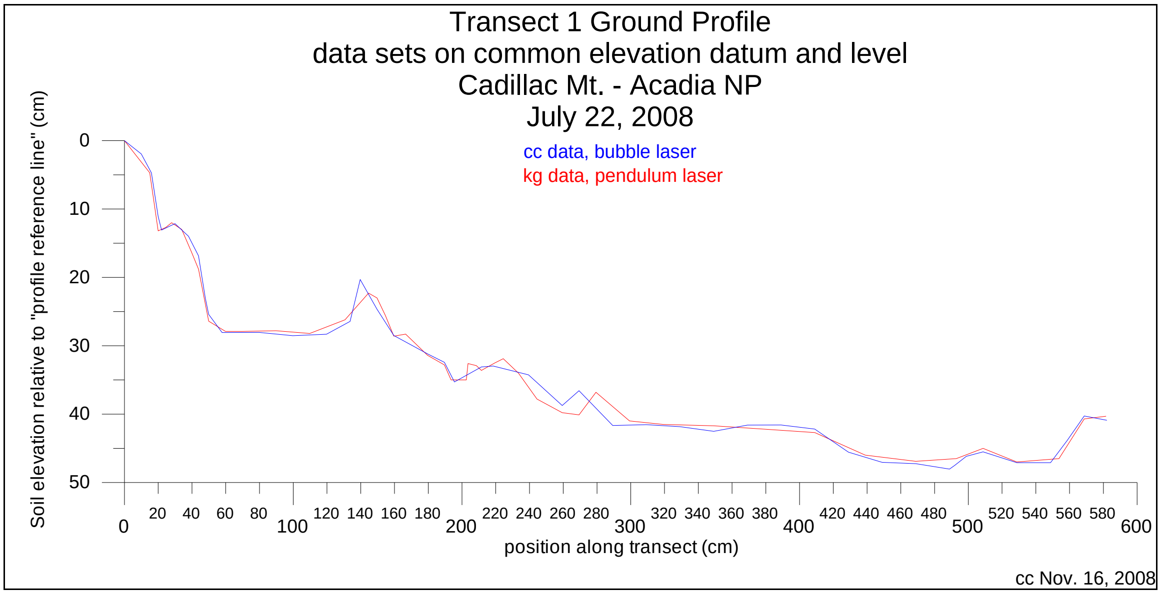
Cole, D.N. 1983. Assessing and Monitoring Backcountry Trail Conditions. Research Paper INT-303. Ogden, Utah: USDA Forest Service, Intermountain Research Stn.

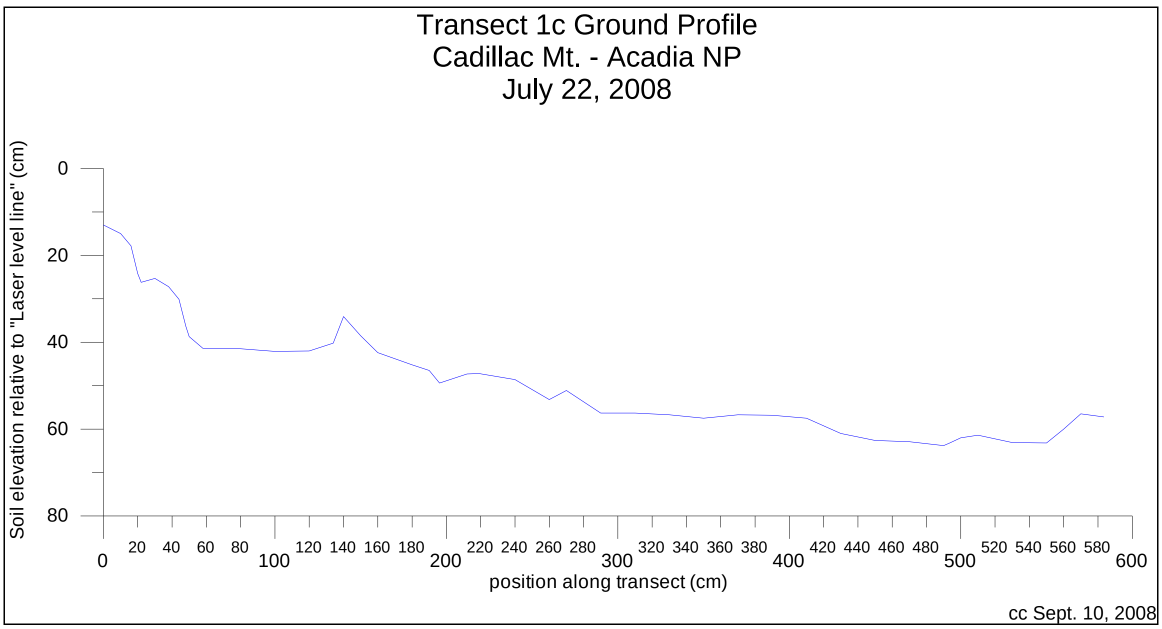
Marion, Jeffrey L. 1991. Developing a natural resource inventory and monitoring program for visitor impacts on recreation sites: A procedural manual. USDI National Park Service, Natural Resources Rpt. NPS/NRVT/NRR-91/06. Denver, CO. 70p.

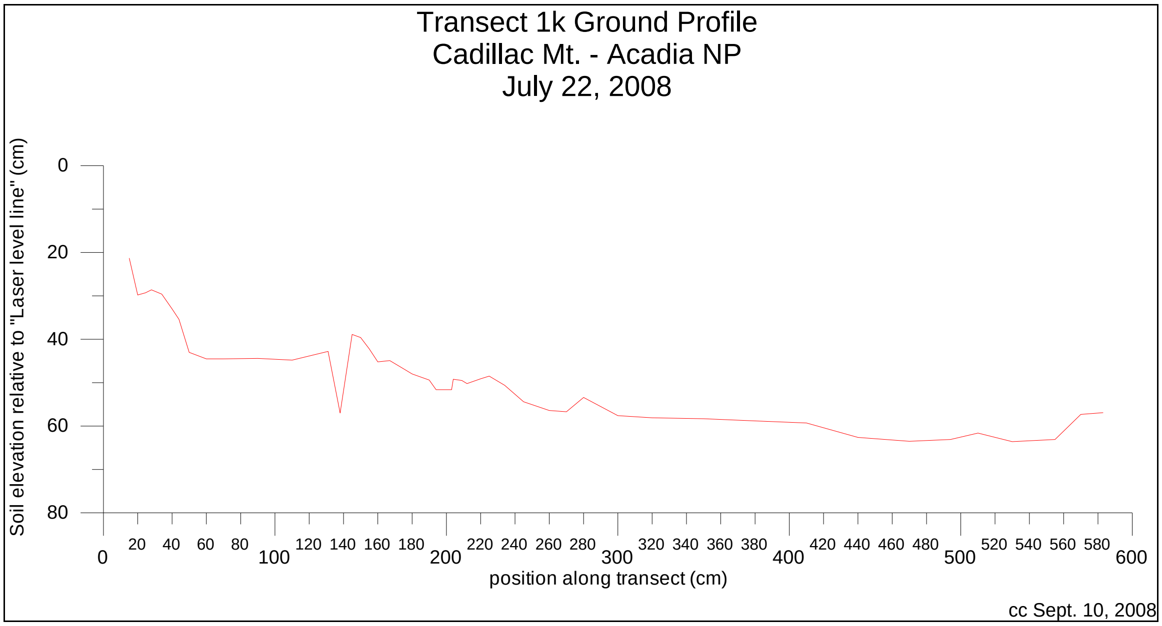
APPENDIX 3: SOIL LOSS TRANSECT RESULTS AND CALCULATION GUIDANCE

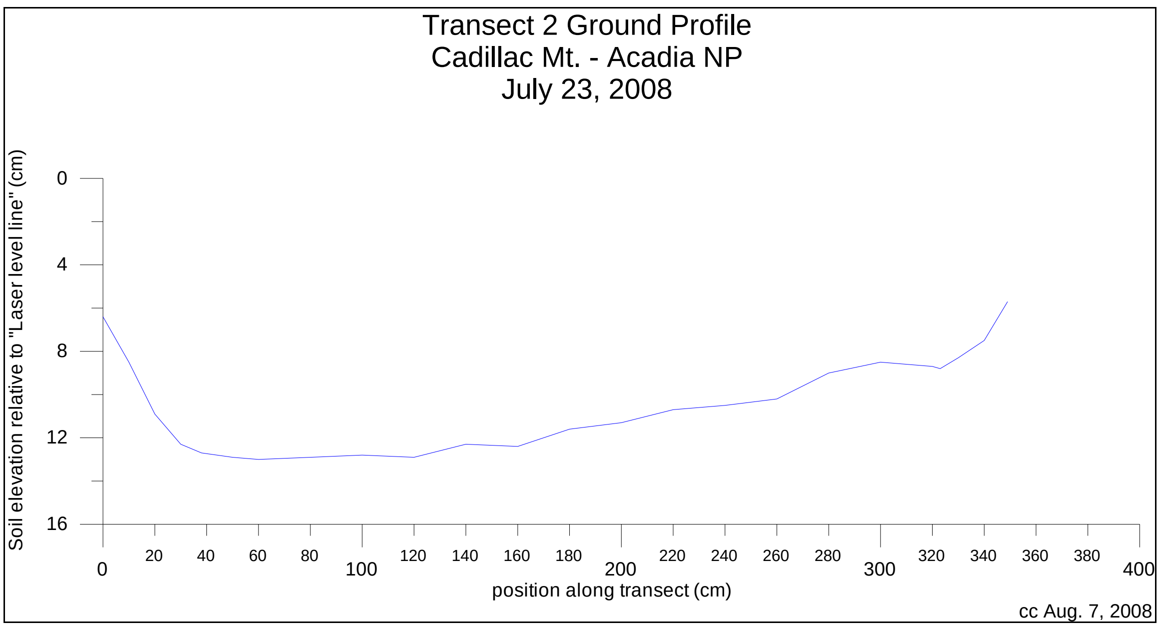
I. Ground profile plots
II. Data sheets
III. Transect photo merges
IV. Profile adjustment procedure
V. Recommended field procedure manual

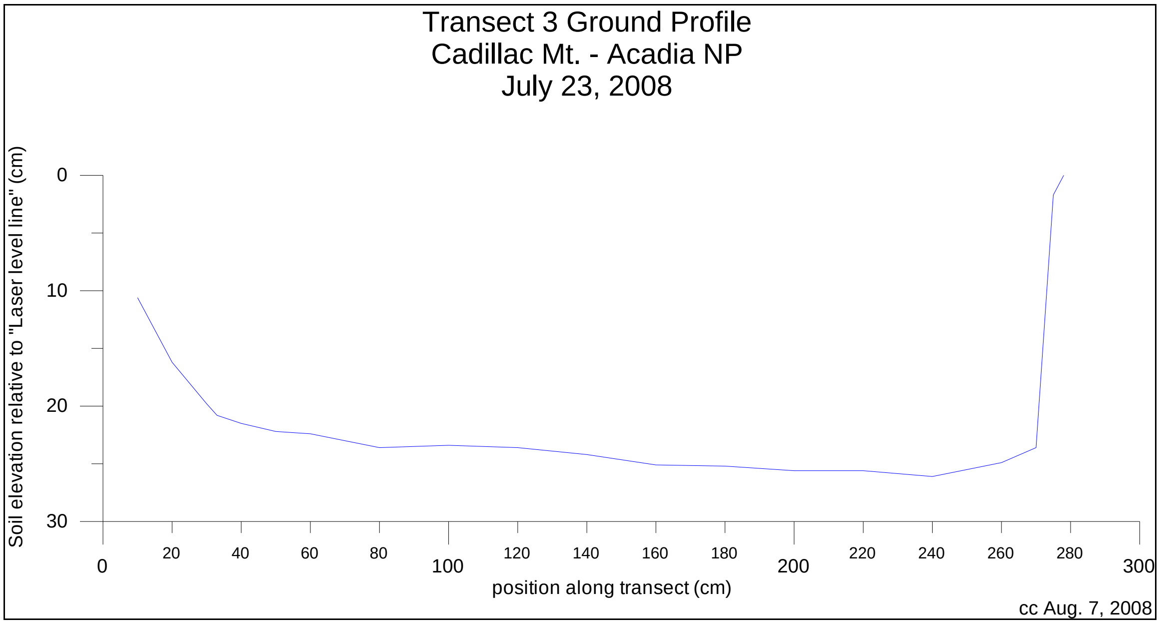
This Appendix contains the data collected as part of our research to develop highly accurate soil loss measurement protocols for the Cadillac Summit. A CD is included with electronic copies of this data, including additional photos and GIS layers.


Transect 1 Ground Profile
data sets on common elevation datum and level
Cadillac Mt. - Acadia NP
July 22, 2008
cc data, bubble laser
kg data, pendulum laser
Soil elevation relative to "profile reference line" (cm)
0
10
20
30
40
50
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400
420
440
460
480
500
520
540
560
580
600
position along transect (cm)
cc Nov. 16, 2008

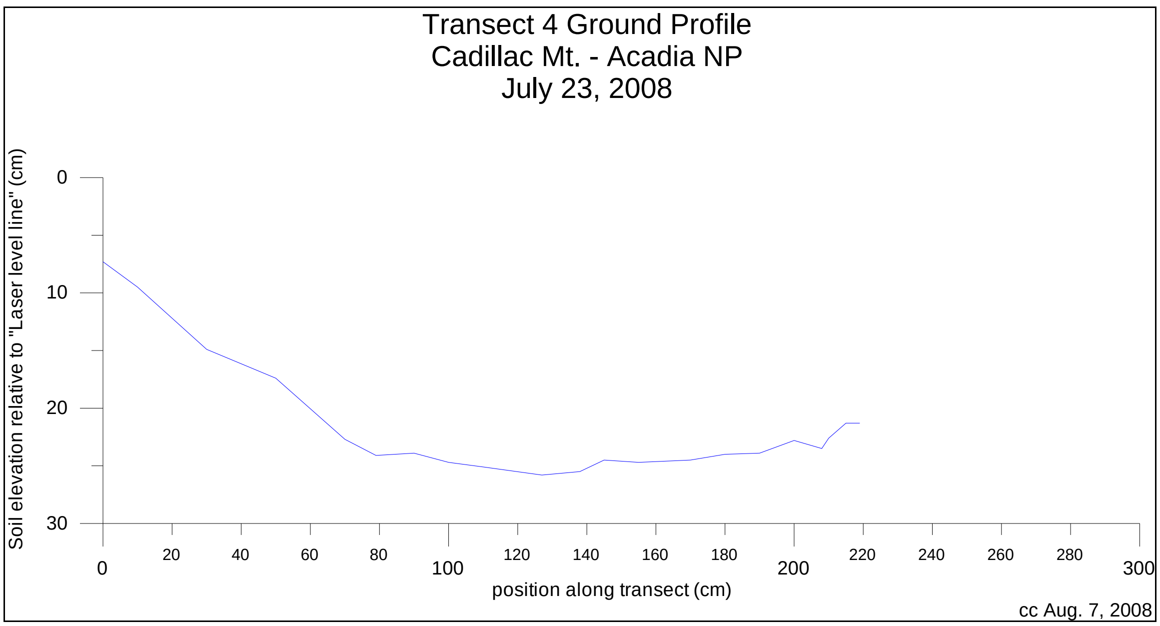

Transect 1c Ground Profile
Cadillac Mt. - Acadia NP
July 22, 2008
Soil elevation relative to "Laser level line" (cm)
0
20
40
60
80
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400
420
440
460
480
500
520
540
560
580
600
position along transect (cm)
cc Sept. 10, 2008


Transect 1k Ground Profile
Cadillac Mt. - Acadia NP
July 22, 2008
Soil elevation relative to "Laser level line" (cm)
0
20
40
60
80
0
20 40 60 80
100
120 140 160 180
200
220 240 260 280
300
320 340 360 380
400
420 440 460 480
500
520 540 560 580
600
position along transect (cm)
cc Sept. 10, 2008

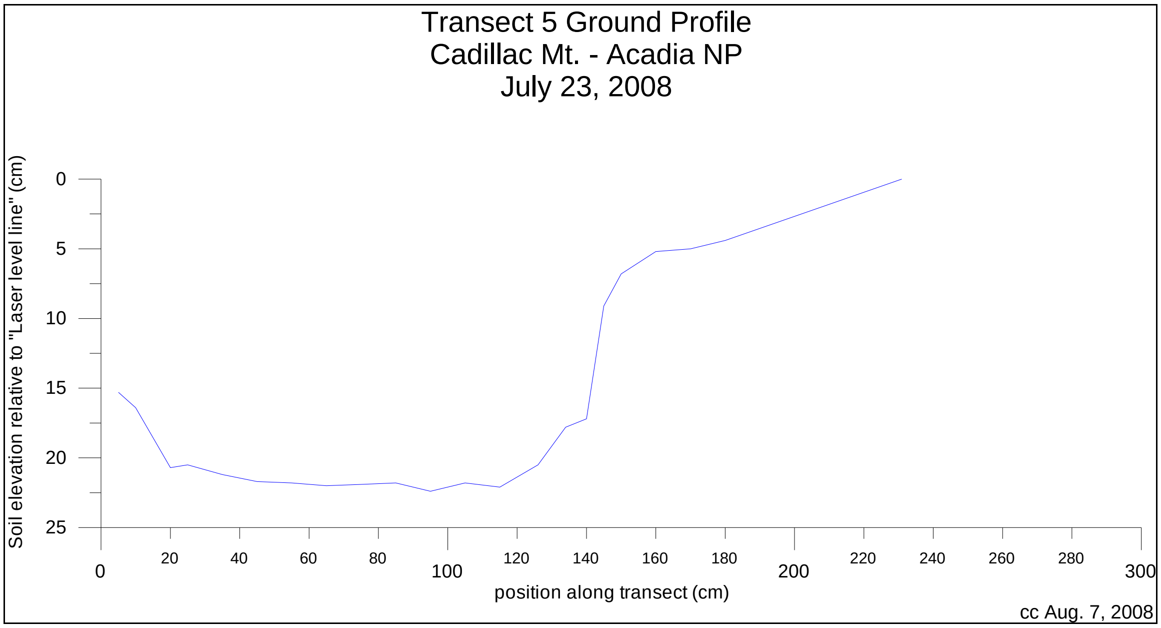

Transect 2 Ground Profile
Cadillac Mt. - Acadia NP
July 23, 2008
Soil elevation relative to "Laser level line" (cm)
0
4
8
12
16
0
20 40 60 80
100
120 140 160 180
200
220 240 260 280
300
320 340 360 380
400
position along transect (cm)
cc Aug. 7, 2008

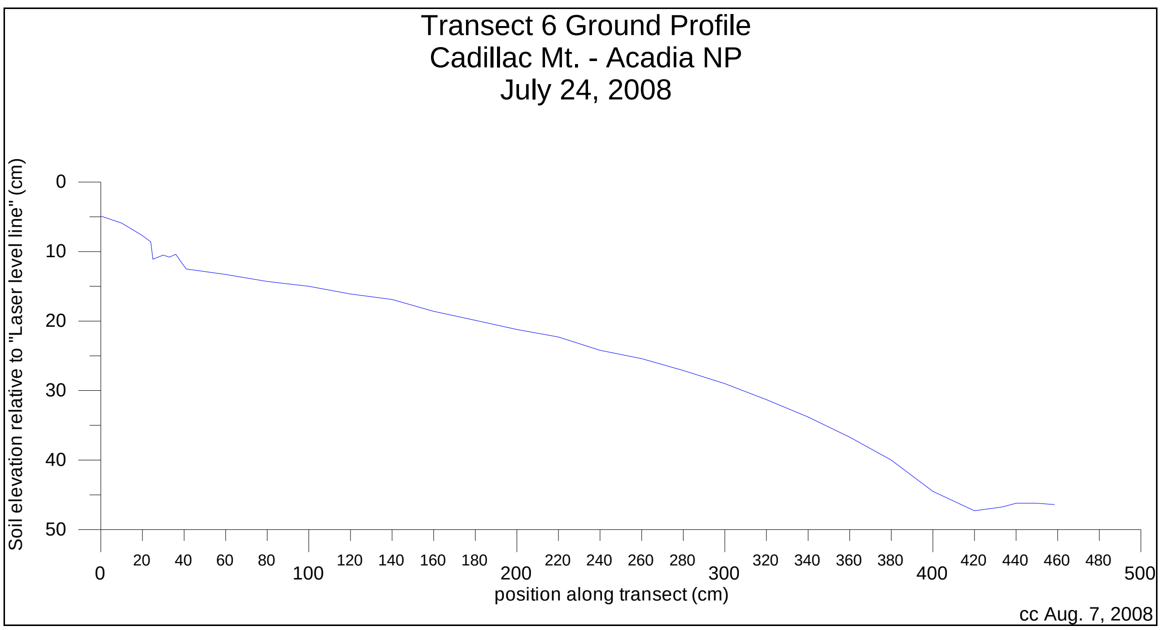


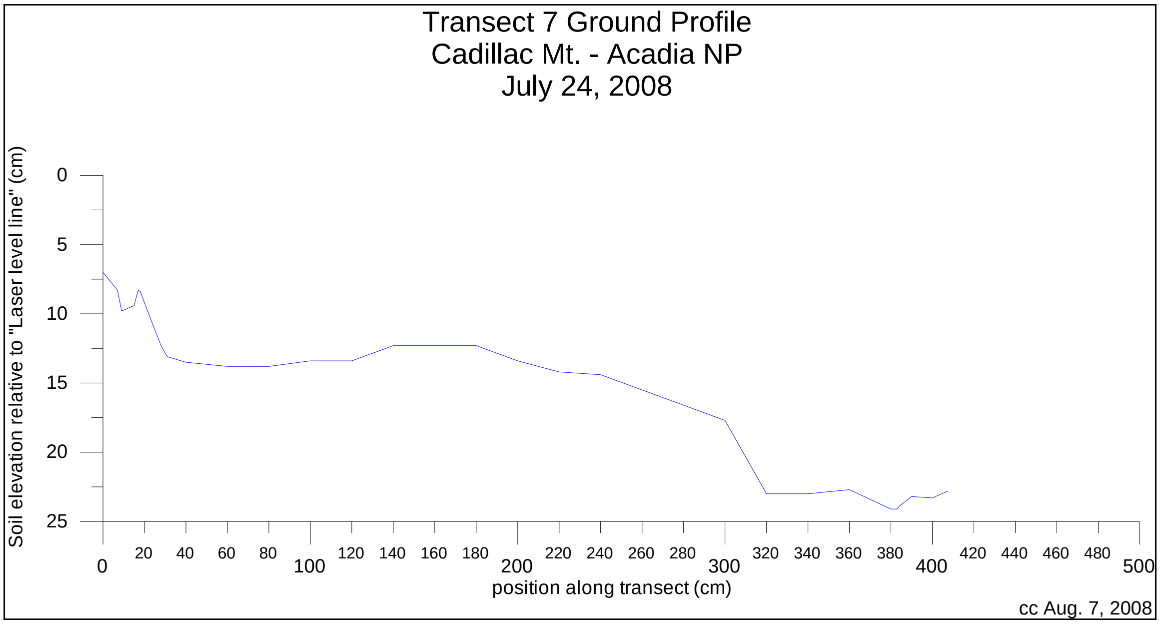
Transect 3 Ground Profile
Cadillac Mt. - Acadia NP
July 23, 2008
Soil elevation relative to "Laser level line" (cm)
0
10
20
30
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
position along transect (cm)
cc Aug. 7, 2008



Transect 4 Ground Profile
Cadillac Mt. - Acadia NP
July 23, 2008
Soil elevation relative to "Laser level line" (cm)
0
10
20
30
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
position along transect (cm)
cc Aug. 7, 2008


Transect 5 Ground Profile
Cadillac Mt. - Acadia NP
July 23, 2008
Soil elevation relative to "Laser level line" (cm)
0
5
10
15
20
25
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
position along transect (cm)
cc Aug. 7, 2008


Transect 6 Ground Profile
Cadillac Mt. - Acadia NP
July 24, 2008
Soil elevation relative to "Laser level line" (cm)
0
10
20
30
40
50
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400
420
440
460
480
500
position along transect (cm)
cc Aug. 7, 2008



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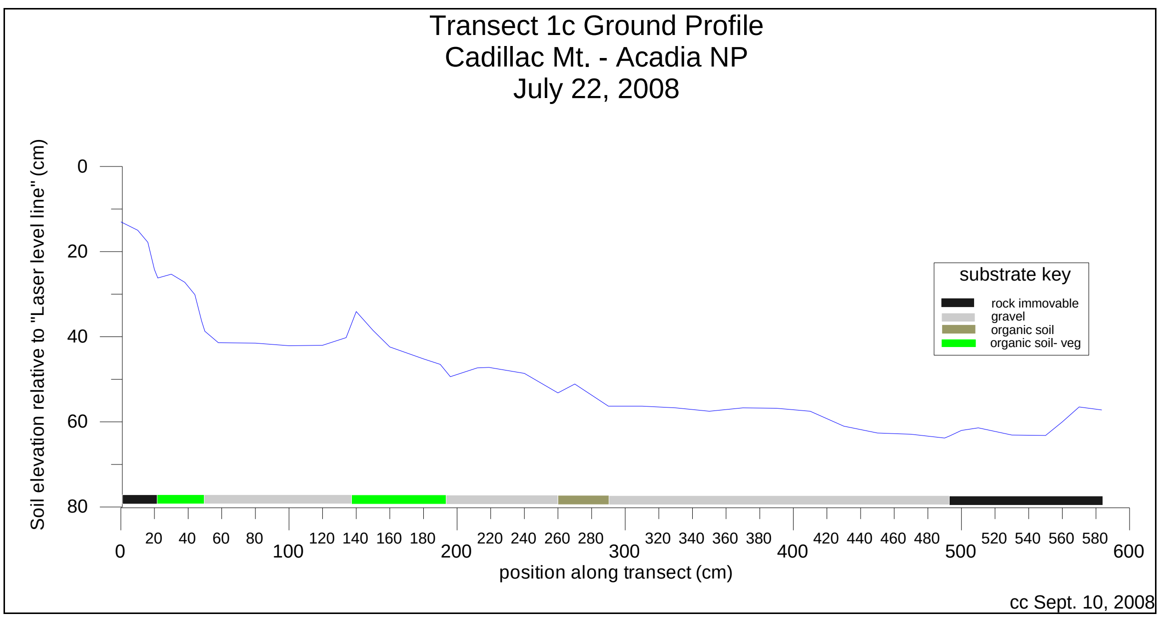


park	Acadia National Park
area	Cadillac Mt.
transect no.	T1-c
by	CC, JW, KG, JM
date	July 22, 2008
laser level	red bubble level
transect length (cm)	583.7
transect bearing (deg mag)	75
fall line slope (%)	3

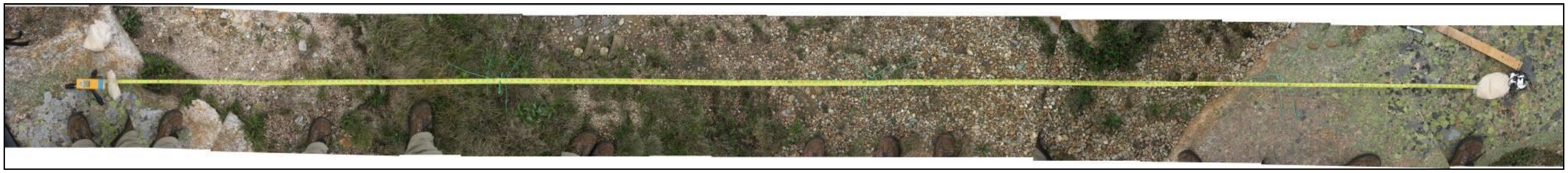
fall line bearing (deg mag)	222
GPS coordinates ref pt A	see Trimble GPS file
GPS coordinates ref pt B	see Trimble GPS file
comments	in exclosure, across some intact soil and blown out soil
Initial Ya	13.0
Initial Yb	57.1

Profile measurement	Xi (cm)	Yi (cm)	substrate
0	0	13.0	RI
1	10	15.0	RI
2	16	17.8	RI
3	20	24.2	OS-V
4	22	26.2	OS-V
5	30	25.3	OS-V
6	38	27.2	OS-V
7	44	30.1	OS-V
8	48	36.3	OS-V
9	50	38.7	G
10	58	41.4	G
11	80	41.5	G
12	100	42.1	G
13	120	42.0	G
14	134	40.2	G
15	140	34.1	OS-V
16	150	38.5	OS-V
17	160	42.4	OS-V
18	180	45.2	OS-V
19	190	46.5	OS-V
20	196	49.4	G
21	212	47.3	G
22	219	47.2	G
23	240	48.6	G
24	260	53.2	OS
25	270	51.1	OS
26	290	56.3	G
27	310	56.3	G
28	330	56.7	G
29	350	57.5	G
30	370	56.7	G
31	390	56.8	G
32	410	57.5	G
33	430	61.0	G
34	450	62.6	G
35	470	62.9	G
36	490	63.8	G
37	493	63.3	RI
38	500	62.0	RI
39	510	61.4	RI

40	530	63.1	RI
41	550	63.2	RI
42	560	60.0	RI
43	570	56.5	RI
44	583.5	57.2	RI
final Ya	12.9		
final Yb	57.2		

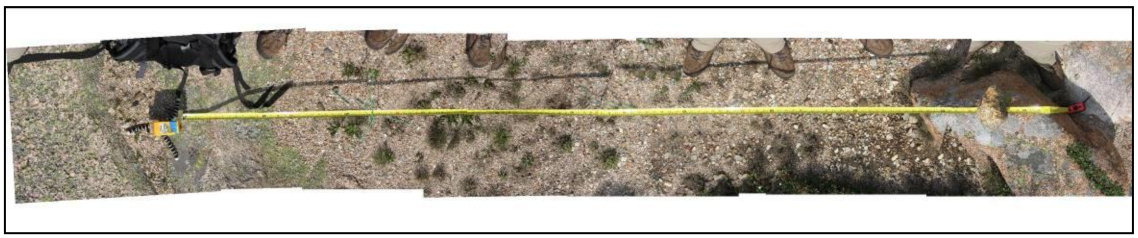
photographs	direction (deg mag)	photo #	comments
overall perpendicular	0	868	
vertical stitch	vertical	869-880	
ref pt A	--	883	
ref pt B	--	884	
other		881,882,867	

Transect 1

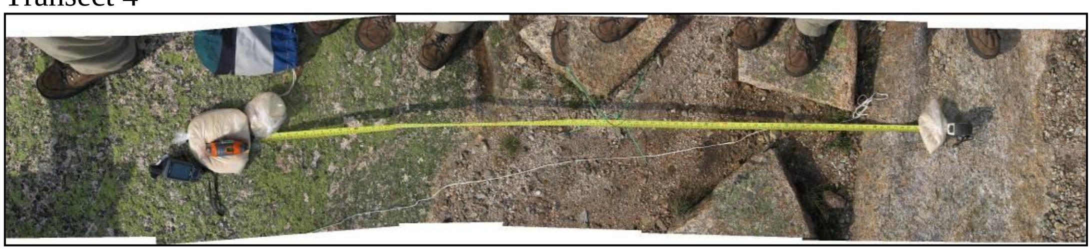


Transect 2

Transect 3



Transect 4



Transect 5

Transect 6

Transect 7

Ground Profile Calculations

This procedure is used to correct two or more profile measurements taken at a transect location. The procedure corrects for slope in the x-direction, the “measuring tape line”, and for differences in height of the “laser level line” and for differences in level at different times.

This set of calculations converts two sets of ground profile measurements, taken at two different times, with, most likely, two different sets of instruments and brings them to a common elevation datum. The common elevation datum is the elevation of reference point A. This procedure assumes the leveling of the two lasers will not be the same within the tolerances required—so brings the two lasers to a common level, based on the elevation of reference point B (one or the other laser is assumed to be correct).

Based on an arbitrary measurement point “i” (see figure 1), where we have the values recorded on the data sheet, $X_{measured}$ and $Y_{measured}$, here are the corrections to get the new values $X_{horizontal}$ and $Y_{corrected}$:

From the sketch: $Y_{measured} = Y_{corrected} + Y_A + Y_{error}$
So: $Y_{corrected} = Y_{measured} - Y_A - Y_{error}$

Defining α as the slope angle of the “measuring tape line” and transect_length as the straight line distance from A to B, we have:
For slope angle: **Error! Objects cannot be created from editing field codes.**
So to get the horizontal X-dimension:

$$X_{horizontal} = X_{measured} * \cos\alpha$$

And for the error in level:
Defining θ as the angle between the two “laser level lines”:

Error! Objects cannot be created from editing field codes.

So: $Y_{error} = X_{horizontal} * \tan\theta$
Remember: $Y_{corrected} = Y_{measured} - Y_A - Y_{error}$
So substituting: $Y_{corrected} = Y_{measured} - Y_A - X_{horizontal} * \tan\theta$

Further substitute: $Y_{corrected} = Y_{measured} - Y_A - X_{measured} * \cos\alpha * \tan\theta$
Noting cos α and tanθ are constants.

To summarize:

$$X_{horizontal} = X_{measured} * \cos\alpha, \text{ and}$$
$$Y_{corrected} = Y_{measured} - Y_A - X_{measured} * \cos\alpha * \tan\theta$$

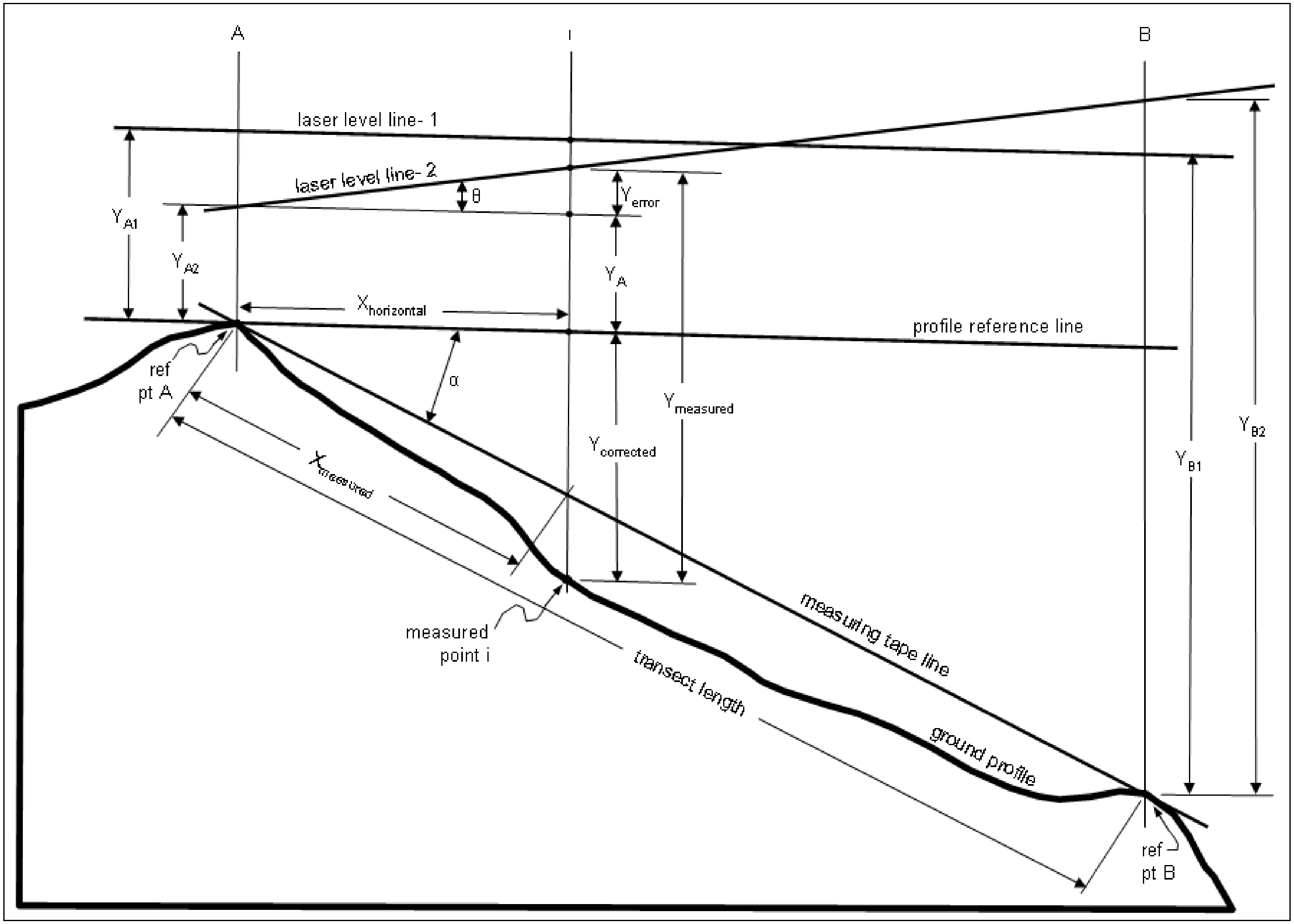


Figure 1: Diagram showing conversion from $X_{measured}$ and $Y_{measured}$ to $X_{horizontal}$ and $Y_{corrected}$.

APPENDIX 4: PHOTO QUAD VISUAL LANDCOVER ESTIMATION PROTOCOLS

This guidance provides a standard method for estimating land cover proportions within the near vertical digital imagery captured atop Cadillac Mountain Summit during the summer of 2008.

Materials:

Digital Imagery (photo ID is the last 3 digits of the file name)
Excel Spreadsheet (use this to record estimates)
Transparency (place over the computer screen to aid in accurate and precise estimates)

Method:

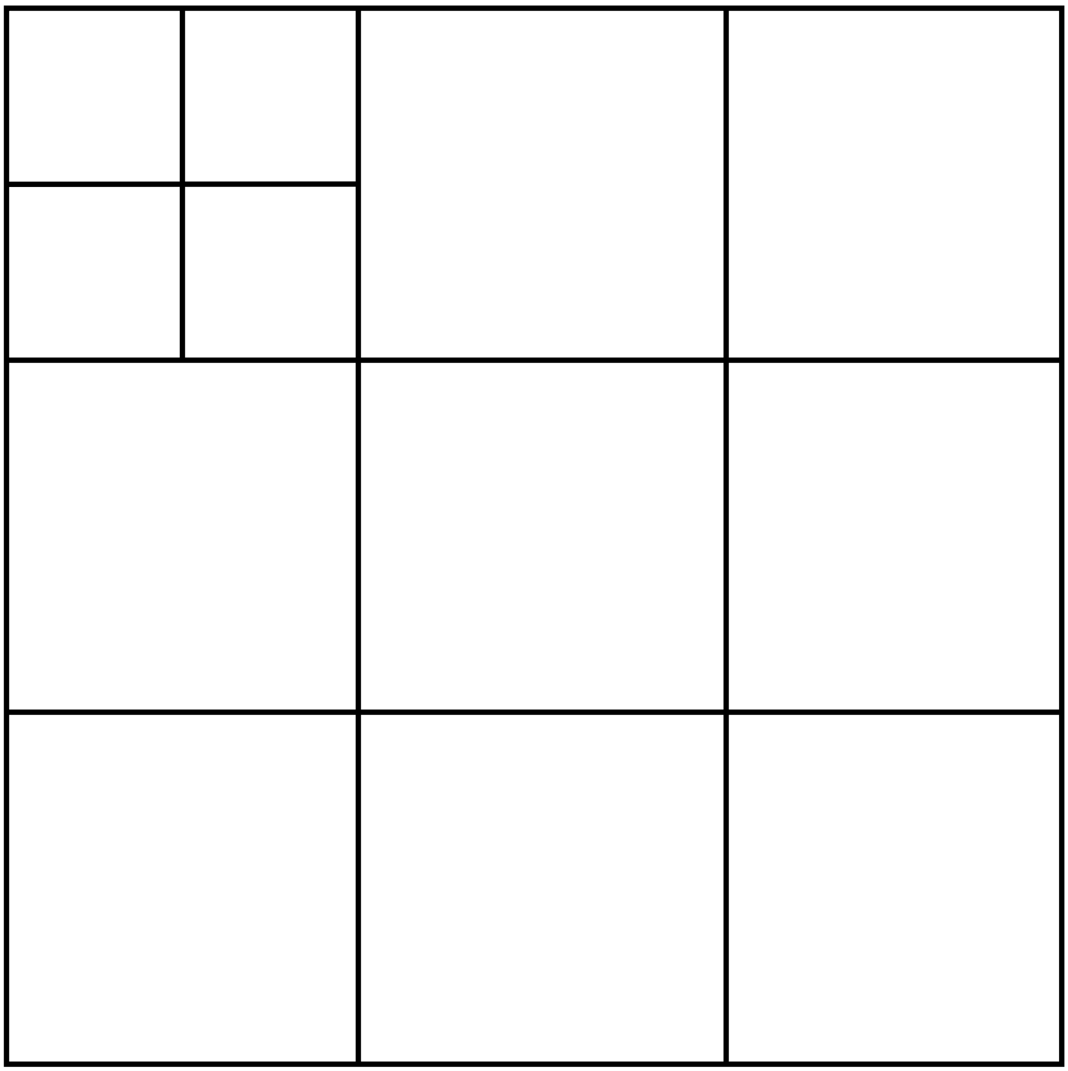
- Open the Excel Spreadsheet (Save As: add your Initials as a suffix to the file name)
- Open the images in a viewer of your choice
    - I have used the Filmstrip function of Windows File Explorer as it allows quick loading and navigation from image to image
    - Using the transparency as an overlay to your computer screen, create a 3x3 grid that "fits" the images (see overlay sample below)
    - Each large cell of the grid represents 11.11% of the image, smallest are 2.75%
    - The cells are an aid to improve accuracy and precision of percentage estimates
    - For each image estimate the percent of the image in each of the 8 classes below
    - On complex images you should mentally "rearrange" and aggregate smaller patches of cover using the transparency grid to aid in your estimates
    - Some categories are more difficult to visualize independently (i.e. lichen vs. rock or senesced vs. live graminoid) In these cases our efficiency and accuracy can be improved by first estimating a percent of the image for the two classes, and then estimating the split between these classes and assigning the appropriate values.

Class Definitions:

Woody – Mostly green woody vegetation (trees and shrubs). When in doubt vegetation was assessed as herbaceous cover.
Herbaceous – Non-woody mostly green vegetation cover.
Graminoids – Mostly green grasses and/or sedges.
Senesced/dead vegetation – Any predominantly tan-colored broad-leafed or grass-like leaves and/or non-leaf bearing woody stems.
Mosses – Include only mosses, noting that some may appear almost black in color and that some lichen are green.
Rock – Bare rock, often pink in color on Cadillac (rare without lichen cover).
Lichen – Rock covered by crustose or foliose lichen ranging in color from white, to green, to grey, including Reindeer lichen.

Gravel/Soil – Gravel is rock that is in loose form (e.g., 2-inch and smaller); this class includes all loose rock fragments and organic and mineral soil that tend to aggregate in the same areas.

Other – This class includes anything not covered in the other classes (e.g., man-made objects such as wooden stakes, rope, shoes, trash, etc.)



Overlay with 3x3 main grid and 2x2 sub grid - create this using a transparency. The size of your overlay will depend on the size, resolution and settings of your monitor.


Woody
Herbaceous (multi leaved)
Mosses Places these in the mosses category


Rock larger than ~2” goes in rock. The rest goes in gravel/soil category
Determine the % of the image that this rock/lichen covers then split that % out by the proportion of rock to lichen within this region

APPENDIX 5: SAMPEPOINT COVER ESTIMATE GUIDANCE

SamplePoint was developed by the USDA Agricultural Research Service Rangeland Resources Research Unit, USDI Bureau of Land Management Wyoming State Office and Berryman Consulting. For more information and a link to download this free computer program visit: http://www.samplepoint.org/

Using SamplePoint for Image Analysis: Training Exercise

1. Select **Options > Select DataBase**
2. Navigate to the folder called *SamplePoint Training* (on the Desktop) and open the Excel file titled *SUMMIT_TRAINING*
    a. A message will pop up informing you of the number of images contained in the data base. In this case, there are 29. Click **Ok** to continue.
    b. The first image will automatically appear on the screen at full size. It helps to look the image over carefully now and make mental notes of the different kinds of landcover you observe (e.g., Is there any exposed soil or patches of moss?)
    c. Below the image is a series of 13 buttons. These are what you'll use to assign landcover classes to the image. These buttons are explained in more detail on the *"Key to SamplePoint Landcover Classifications"* guidance included below.
3. On the left-hand side of the screen, select **Train**. The database has already been classified and your input will be compared to that information.
4. Click **Begin** at the top of the screen.
    a. The screen will zoom in to a point on the image, and you will see a red crosshairs. While you can gain context from the image around the crosshairs, you must classify what is at the exact center of the crosshairs, not the dominant feature around them (for example, if the center of the crosshairs falls on a shadow just off of the edge of a leaf on a shrub, classify it as "Other," not "Shrub").
    b. You can zoom in and out as you please by changing the number in the box next to **Zoom** and clicking **Refresh**. The value you enter is in X, so 8 means that you are zoomed in 8 times.
    c. You may also choose to uncheck **Block Zoom**. This will make the image load faster and appear less pixilated, though it will appear slightly blurred.
5. You will work through a total of 100 points in each photo. If your classification matches the information in the database, you will automatically move on to the next point. If not, an error message appears with your input and the "correct" classification.
6. When you have completed all 100 points, you will receive a message to click **Next Image** at the top of the screen. The next image will load and appear at full size. You will also get a scorecard with the results of your classification of the previous image.
7. If your eyes start to get tired, take a short break. The first few images will be tough as you get used to looking at everything zoomed in. You may also change the color of the active crosshairs by selecting **Options > Change Crosshair Color**. You may choose red, blue, bright green, or teal. I find that the teal crosshairs is less straining on the eyes but still shows up well against the image.

Class Name	Description	Photographic Example
Gram	Graminoids – grasses, sedges, and rushes. Basically anything that looks like grass	
Shrub	Shrub – plants with woody stems, less than 5-6m in height. This will include all trees	
Forb	Forb – flowering plants with non-woody stems that are not graminoids	
Fern	Fern – broad leaved, spore dispersing plants	
Moss	All mosses	
Rock	Bare rock (no lichens)	

Class Name	Description	Example
CrustLc	Crustose lichen – lichens that form a crust that is tightly attached to the substrate on which they are growing	
Foliose	Foliose lichen—“leafy” lichens composed of lobes that are relatively loosely attached to the substrate on which they are growing	
OrgSoil	Organic soil – soil that is composed mostly of organic matter. Dark in color, fine textured, with plant residue or roots sometimes visible	
MinSoil	Mineral soil – soil that is mostly mineral with very little or no organic material. Usually lighter, “grainy,” often looks like sand or gravel	
DeadWd	Dead wood – standing dead wood (for example, small dead trees or shrubs)	
Litter	Organic material that has been detached from its stem and is on the ground. Includes sticks, small pieces of wood, detached leaves, and sections of stem	
Other	Anything that cannot be classified as any of the above. Includes cable, string, trash, boots, toes, legs, pants, hair, etc.