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Trail impact monitoring in Rocky Mountain National Park, USA

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Abstract

This paper examines impacts of increased visitation leading to human trampling of vegetation and soil along several trails in Rocky Mountain National Park (RMNP) to understand how abiotic factors and level of use can influence trail conditions. RMNP is one of the most visited national parks in the USA with 3.3 million visitors in 2012 across 1075 km^2 and 571 km of hiking trails. 95 % of the park is designated wilderness making the balance between preservation and visitor use challenging. This research involves the application of trail condition assessments to 56 km of trails to determine prevailing factors and what, if any, connection between them exist. The study looked at a variety of inventory and impact indicators and standards to determine their importance and to develop a baseline condition of trails. The data can be used for future comparison and evaluation of development trends. We found that trail widening (mean trail width 88.9 cm) and soil loss (cross sectional area 172.7 cm^2) are the most visible effects of trail degradation. Further statistical analyses of data identified the role and influence of various factors (e.g. use level and topography). Insights into the influence of these factors can lead to the selection of appropriate management measures to avoid or minimize negative consequences from increased visitation.

1 Introduction and problem overview

Recreational activities in protected areas have been increasing creating the need to improve understanding the impacts and management (Hammitt et al., 2015; Chrisfield et al., 2013; Monz et al., 2013). The trampling of vegetation and soil by hikers (Cole, 1989; Bright, 1986) is often a cause of land degradation in national parks. Recreational trails are often a source of negative impacts on the persistence of threatened, endangered, rare and keystone species (Ballantyne and Pickering, 2015). Trampling especially in tundra ecosystems may lead to altered environmental conditions, including decreased infiltration capacity and nutrient cycles in soils, and more extreme temperatures at the soil surface (Chrisfield et al., 2012). To date, large amounts of research is focused on the impact of visitors to soil and vegetation including monitoring and modelling (Dixon et al., 2004; Farell and Marion, 2001). A variety of efficient methods for evaluating trails and their resource conditions especially in sensitive and vulnerable areas (alpine environment) have been developed and described in the literature (Jewell and Hammitt, 2000; Hawes et al., 2006; Ólafsdótirr and Runnström, 2013; Tomczyk and Ewertowski, 2011). A review by Marion and Leung (2001) concluded that the point sampling method provides accurate and precise measures of trail characteristics that are continuous or frequent (e.g. tread width). Ground-based surveys are fairly accurate (with GPS), use existing staff and resources and provide immediate results. On the other hand there are also some limitations of point sampling techniques – e.g. time consumption (Hill and Pickering, 2009).

Parks and protected areas are often set aside for conservation and recreational purposes, and become some of the most sought after vacation areas in the world creating conflicts between conservation and recreation. In the US, National Park Service (NPS) Units receive approximately 280 million visitors per year (IRMA, 2014). Couple this extensive visitation with the mission of the NPS, which is to protect and preserve both natural and cultural resources while providing for the freest opportunities for public enjoyment and recreation, and conflict between conservation issues and visitor use occur. Striking a balance between these competing goals often force land managers to make compromises between impacts from visitation and protection of resources.

Parks apply a wide range of tools and techniques to manage impacts from visitor use. By providing a network of formal trails, protected areas can limit negative trampling impacts and prevent widespread degradation that would be caused by a less structured pattern of visitor activity and traffic (Marion et al., 2011). To balance resource protection and visitor experience several frameworks have been developed to guide management decisions (Manning, 1999). These frameworks use numerical standards for biophysical or social condition indicators and set limits to define the critical threshold between acceptable and unacceptable change in resources and social conditions (Kim and Shelby, 2006). Baseline data and future monitoring can also be used to compare past conditions with future conditions. If actual conditions are above quantitatively defined standards, managers can effectively deal with these factors to improve or stabilize the conditions. Such visitor impact monitoring programs can provide managers reliable information necessary to evaluate resource protection policies, trends, strategies and measures (Vistad, 2003). However many authors stated that visitor impacts on the ecological conditions of an area are influenced more by visitor behavior, park infrastructure, and the resilience of soil and vegetation and less related to overall use levels (McCool and Lime, 2001). For example sustainable usage levels depend on a range of factors including extent of trail hardening and frequency of trail maintenance (Washburn, 1982).

To better understand use and associated resource impacts a visitor and trail monitoring program needs a diverse set of indicators that evaluate changes over time (Leung and Marion, 2000). Most commonly used trail indicators include: the number, length and density of visitor-created trails along with tread. Soil loss, the most ecologically significant trail impact, is less common though can be efficiently determined by measuring maximum incision or cross sectional area at points along the trail (Olive and Marion, 2009). Other problems include visitors participating in a variety of recreation activities (hiking, camping, horseback riding), each of which contributes a unique impact on natural resources (vegetation, soil, water, wildlife). Some authors are comparing and assessing the impacts of different recreation activities (hiking, mountain biking, horse riding) on vegetation and soils (e.g. Pickering et al., 2010; Wilson and Seney, 1994). There is limited research on the ecological impacts of tourism and recreation in some parts of the world (Barros et al., 2015). Existing studies documented a range of impacts on vegetation, birds and mammals including changes in plant species richness, composition and vegetation cover and the tolerance of wildlife to visitor use. Comparable studies especially on high alpine environments are needed to predict the effects of topographic and climatic extremes (Nepal, 2003).

Conducting formal trail surveys provides information for a number of important management questions and decisions though is commonly overlooked due to funding constraints. Information about trail conditions can be used to inform the public about trail status, justify staffing and financing, evaluate the acceptability of existing resource conditions, understand relationships between trail impacts and the controlling mechanism, identify and select appropriate management actions and determine the effectiveness of implemented actions. This paper presents research and assessment of impacts to the trail network of the RMNP study area to understand how abiotic factors such as grade, elevation, surface type and trail slope alignment can influence trail conditions. We also want to understand how visitation type (e.g. people vs. horses) and level of use can impact trails. Finally our last goal is to determine which factors are prevailing and what connection between factors exist. This would help managers reduce the effects of visitor use on natural resources of the park.

2 Study area

Rocky Mountain National Park (RMNP) is located in northern Colorado (USA), comprises an area of 1075 km^2 and provides exceptional access to wild places for visitors to recreate, experience solitude and experience outstanding beauty (Fig. 1). The dramatic elevation range within the park spans from 2316 to 4346 m, which creates a highly complex and steep topographic gradient allowing for diverse vegetation communities. Fragile alpine tundra encompasses one-third of the park area. The underlying geology of these mountains are also highly complex, though are primarily granitic. Severe climatic conditions and thin soils have created a fragile environment at higher elevations throughout the park that is neither resistant nor resilient to human use (RMNP, 2013). Over the past several decades temperatures have been increasing and precipitation patterns have been highly variable with increased drought years followed by extreme rain events and record snow packs, causing varying degrees of freeze thaw actions and greater spring runoff events. Yearly visitation over the past decade has hovered

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around 3 million visitors a year with total number of recreation visitors in 2012 being 3.3 million. The busiest tourist season is the summer months (June–August), but in recent years the heaviest visitation days have occurred during the weekends of late summer early fall due to the elk rut and foliage change. Overnight as well as day use has steadily increased over the past several decades resulting in more impacts from visitation (RMNP, 2001).

Early studies focused on impact of visitors on natural ecosystems in RMNP (e.g. Willard and Marr, 1963) stated need to develop a system of evaluating day use destination sites, document trends in day use, develop guidelines, install flip signs, voluntary permit or self-registration system and set concrete use limits (e.g. for parking). Later works are devoted especially to monitoring of trail impacts (Summer, 1986; Benninger-Truax et al., 1992; KellerLynn, 2006; Pettebone et al., 2009).

Monitoring visitor use focused on vegetation and soil impacts is important in alpine areas, climbing areas and riparian areas where the information can help with determining thresholds of degradation (NPS, 2010). Severe climatic conditions and thin soils have created a fragile environment at higher elevations throughout the park that is neither resistant nor resilient to human use. The loss of soil and vegetation from high use and unacceptable behaviors of visitors are a principal concern. Besides educating of visitors about principles (e.g. stay on the trail), monitoring of visitor use numbers, the results of this research can help inform park managers.

Approximately 571 km of hiking trails provide visitors with recreation opportunities throughout the park (RMNP, 2013; Fig. 1). Some of the current trail system evolved from game trails used by Native Americans, then explorers and herders and finally adopted by the National Park Service. A lot of the trails were built or improved by the Civilian Conservation Corps (CCC) during the 1930's. These trails span the entire elevation gradient running across valley bottoms and ridgetops. RMNP is divided into ten planning units based on similar physiographic features and visitor use patterns (RMNP, 2000). Evaluated trails are situated in several planning units (Fig. 1; Front Range, Longs Peak, Wild Basin, Roaring River, Trail Ridge). Each planning unit are

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specified with trail project priorities (safety of visitors, mitigation of resource damage) and cost estimates. Since 2008 there are new Federal Trail Data Standards which include four fundamental concepts that are cornerstones of effective trail planning and management (trail type, trail class, managed use, designed use). Although not entirely new, these interagency concepts provide an integrated means to consistently record and communicate the intended design and management guidelines for trail design, construction, maintenance and use.

3 Methods and analysis

During August 2013, we applied impact assessment procedures to eight formal and informal trails (56 km) within RMNP. These eight trails, a subset of the entire trail system, were selected because these trails provide a unique look at variation of impacts along an elevation gradient and visitor use gradient while representing the greatest possible spatial extent of RMNP. Some of the trails (or sections of trails) are used not only by hikers but also by other user groups such as equestrians (about 80 % of the total trails maintained in the park are open to commercial and private stock use). Four trails were evaluated on the north side of the park: Saddle trail (SDDL), Ute trail West (UTEW), Ute trail East (UTEE) and Mount Ida trail (IDAM), three on the south side of the park: Flattop Mountain trail (FLTM), Boulder Field trail (BLDF) and Thunder Lake trail (THLA). Also one short section of an informal trail: Old Fire trail (OFIR), was measured with detailed sampling (30.5 m interval) – see Table 1 and Fig. 2.

Trail sampling for each of the eight trails involved taking replicable measurements at a number of determined locations in order to calculate overall estimations of trail conditions. We used point sampling methods to generate accurate and precise data on trail conditions (Marion et al., 2011). This was used to develop useful and appropriate baseline data to monitor selected environmental indicators and standards of quality. A 152 m point sampling interval, determined using GPS (Garmin GPSmap 60 CSx) and measuring wheel (Rolatape RSL 204-5), was selected and employed based on the findings, efficiency and feasibility of replication and was thought to best represent the length of each trail. This interval provided the appropriate number of sample points allowing statistical analysis and ability to characterize trail conditions.

At each sample point, a single transect was established perpendicular to the trail tread with endpoints defined by the most visually obvious outer boundary of trampling-related disturbance. These boundaries are defined by pronounced changes in ground vegetation height (trampled vs. un-trampled), cover, composition or when vegetation cover is reduced or absent and by disturbance to organic litter or lichen (intact vs. pulverized). We adopted criteria described by Monz (2000) and Lance et al. (1989) for measurement consideration and definition of the trail tread boundaries – receives the majority (> 95 %) of traffic (Marion et al., 2011). To assess trail width, the distance between these disturbance-associated boundaries was measured with tape rule (Stanley Lever Lock 25′). The difference between intended vs. actual trail widths was assessed as trail width difference according trail data standards. Additionally the grade of the trail and the dominant fall-line (landform grade) was recorded at each transect location.

Trail slope alignment angle (TSA) was assessed at each sample point as the difference in compass bearing between the prevailing landform slope orientation (i.e. aspect) and the trail's alignment at the sample point. For example, TSA of contour-aligned trail would equal 90° while a true "fall-line" trail (aligned congruent to the landform slope) would have a TSA of 0°. Trail grade, trail slope and alignment angle were measured using clinometer and compass (Suunto Tandem). The quotient of trail grade and landform grade was calculated as slope ratio (IMBA, 2004). To assess tread surface composition we used the following categories: bare soil, vegetation, organic litter, roots, rock and gravel, wood and man-made materials. For each category, the percent of trail width was recorded to the nearest 10 %. An occurrence of additional secondary trails that paralleled the survey trail at each sample point was marked as well as previous remarkable side-hill construction work at each sample point.

To determine whether there was soil loss (cm^2) at a sample point, we employed a fixed interval method cross sectional area (CSA) analysis, adopted from Cole (1983) and described as Variable CSA method (Olive and Marion, 2009). To establish a cross section temporary stakes were placed at positions that enabled a cord measure to be stretched along what was believed to represent the original land surface for fall-line trails or the post-construction tread surface for constructed side-hill trails. Vertical measurements from the cord measure to the trail substrate surface were taken at a fixed interval of 12 cm for all trails. This measure included soil loss from water or wind erosion, soil compaction of the trail substrates and soil displacement from traffic. CSA was calculated for each sample point using spreadsheet formulas in Microsoft Excel, where V = vertical distance measurements, L = interval on horizontal taut line (Cole, 1983). Trail condition measures were calculated for each trail and for all trails combined, including area of disturbance, CSA and mean trail width and depth.

$$\mathrm{CSA} = (V1 + 2V2 + \ldots + 2Vn + Vn + 1)/2 \times L\ .$$

The ruggedness or roughness of the trail surface was calculated for each sample point from measurements taken to compute CSA estimates as the standard deviation of the vertical measurement at each transect. To ensure repeatability of this work digital photographs were taken with a camera (Panasonic DMC-SZ1, 16.1 megapixel resolution) along with recording GPS coordinates at each transect to all future resampling events to occur along the same transects. Photographs were also utilized to create two additional attributes for each trail transect – trail substrate class and trail borders. Based on field observation by trail maintenance staff, use levels (high > 100 users a day/medium 50–100 users a day/low < 50 users a day) and type of use (hiking only/ hiking + stock use) were assigned to each trail segment. Elevation of each sample point was recorded and three main categories according vegetation cover created: above 3505 m a.s.l. alpine tundra, 3505–2896 m a.s.l. spruce/fir and below 2896 m a.s.l. lodgepole pine (RMNP, 2001).

Spatial data were transferred from GPS to EasyGPS and maps were created in ArcGIS Desktop and ArcMap 10.2 applications. Statistical data were transferred to Microsoft Excel and to statistical system SPSS 19 for further analysis. Originally all suit-

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able statistical procedures (ANOVA, non-parametric ANOVA Kruskal–Wallis test, two sample Mann–Whitney test, correlations (both classic Pearson and robust Spearman) and linear regression analyses) were performed to investigate relationships between dependent and independent variables. Nonparametric tests were used because the data do not meet normality assumptions. Analysis focused primarily on understanding the dependent variables of interest: trail width and CSA soil loss. Linear regression modelling as dependence of soil loss variables to grade variables was done. But the results were unsatisfactory (e.g. regression coefficient of determination below 10 %). That is why we tested also robust nonparametric data mining decision trees implemented in SPSS to gain multivariate models of tread widths vs. all relevant indicators. In SPSS there are three types of decision trees: CHAID, CRT and QUEST. For our purpose CRT (cascade routing tool) decision tree appeared as the most suitable.

4 Results

4.1 Trail condition indicators

We assessed 361 sample points along a total length of 55.43 km for seven trails within RMNP. One short informal trail (1.42 km, 48 points) was surveyed though we excluded this trail from the overall statistical analyses since sampling methods differed slightly.

Approximately 13 % of the trails are located on flat terrain (0–2 % grade), 24 % of the trail system has grades exceeding 15 % and only 5 % of the trails have grades exceeding 30 %. The mean grade of trails is 11.4 %. It should be noted that many of the excessively steep alignments have constructed rock steps or ascend exposed rock faces, which are not susceptible to soil loss. Regarding trail's slope alignment angle, only 6 % of trails are aligned within 22° of the landform aspect or fall line. Mean elevation of the evaluated points is 3356.7 m above sea level (Table 2).

Trail width maximum is 193 cm with a mean of 89.9. Less than 14 % of the trails exceed 1.2 m in width. Mean trail width difference was 56.9 cm, indicating that trails are

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generally wider than intended by trail data standards. Maximum incision ranged from 0 to 19.1 cm with a mean of 7.1 cm. Cross-sectional area soil loss measurements (CSA) ranged from 0 to 1510 cm^2, with a mean of 444.5 cm^2. A more representative measure of trail incision is provided by calculating mean trail depth from the vertical measures recorded to compute CSA. This measure ranged from 0 to 12.9 cm with a mean of 4.1 cm (Table 3).

Finally, assessments of the tread substrate as a proportion of transect width are used to characterize the typical trail system substrates described in Fig. 3. The predominant tread substrate is rock and gravel (39.5 %), followed by soil (36.5 %), vegetation (10.5 %), organic surface litter (9.0 %), roots (3.7 %) and mud (0.5 %).

4.2 Trail conditions by classic analyses

From the dependencies it was identified that the greater incidence of secondary treads is connected with higher median of trail slope ratio (0.69 vs. 0.5; Wilcoxon test, p = 0.021) and lower median of trail slope alignment (50 vs. 60°; Wilcoxon test, p = 0.020). Difference of trail grade for secondary treads is not significant.

When looking at side-hill trails, there is higher median of tread width (109 vs. 86 cm; Wilcoxon test, $p < 0.001$). The difference of maximum incision for side-hill trails is not significant.

Results for different use level are highly significant for medians of trail width (63.5 vs. 96.5 vs. 114.3 cm), maximum incision (5.7 vs. 6.3 vs. 7.6 cm) and soil loss (251.6 vs. 393.5 vs. 574.2 cm^2); Wilcoxon test, $p < 0.001$. Increased visitor use lead to greater mean values of width, soil loss and maximum incision of trail (medians of maximum incision for low and middle use level are not different). Difference of tread width difference by use level was not significant (see Table 4 and Fig. 4).

When comparing two groups of visitors (hikers and horseback riders), the Wilcoxon test resulted in medians that were greater for horseback riders: trail width (109.2 vs. 66 cm; $p < 0.001$); maximum incision (6.9 vs. 6.3 cm; p = 0.020) and soil loss (483.8

vs. 296.7 cm^2; $p < 0.001$). Contrary to this, tread width differences were smaller for horseback riders than hikers (17.8 vs. 20.3; $p = 0.009$).

Rugosity can strongly influence existence of secondary treads and trail width. After analyses we confirmed significant dependence only for some trails (e.g. Mann–Whitney test showed dependence of rugosity vs. secondary treads occurrence on Ute West trail and linear dependence on Mount Ida trail between rugosity and trail width). We need to highlight that results for each of the trails are not the same for all variables so any generalization and subsequent interpretation must be cautious and exercised with respect to local conditions (e.g. in case of previous results existence of natural or human induced barriers along trails which prevent trail widening) and number of sample points.

When soil loss was analyzed more deeply, correlation coefficients showed any meaningful dependence between soil loss, trail slope ratio and trail slope alignment. Maximum incision is significantly dependent on trail and landform grade. Trail width on average decreases with increasing elevation – smaller number of visitors (the higher elevation, the narrower trail). For maximum incision the dependence is positive (incision is in average greater for higher elevation) – influence of rough weather and missing forest canopy (susceptibility to erosion).

4.3 Decision trees

Because interpretation of results is rather complicated we tested also data mining decision trees to gain meaningful results. For modelling tread width dependence tree diagram (Fig. 5) shows that the use level is the best (= the most significant) predictor of tread width. The proportion of tread width variance explained by CRT regression tree model is 55 % which indicates a good model. From all used potential indicators of tread width five indicators are used in CRT regression tree: use level, name of trail, trail substrate – vegetation, elevation and maximum incision.

5 Discussion and management implications

National Park Service units are charged with providing opportunities for recreation along with protection and preservation of natural and cultural resources and ecological processes. This research provides information on the impacts of visitor use to trails and which abiotic factors are the most influential to trail conditions. These types of information can serve as the basis for management of visitors. This research used a variety of inventory and impact indicators and the information obtained in this study can also be used to assess future trail conditions as it serves as data for the current condition of trails. These data can be used for the evaluation of trends which allows for more informed management decisions. Our work supports and emphasizes the use of factors such as trail widening and soil loss to be the most significant types of trail degradation.

In literature we found many studies related to trail impacts monitoring. Dixon et al. (2004) used two indicators – track depth and track width. Analysis reveals that track depth and rates of erosion are strongly influenced by track type and to a lesser extent by usage, while track width is influenced mainly by usage and track bogginess. Slope of the path and the number of visitors were two main factors explaining width and depth (Selkimaki and Mola-Yudego, 2011). Tomczyk and Ewertowski (2013) discovered that no connection was demonstrated between amount of use (number of visitors) or type of use and the amount of soil loss or deposition. Study of Jubenville and O'Sullivan (1987) concluded that, vegetation type and slope gradient to trail erosion explained not much of variance in soil loss (could be explained by trail design and permafrost in Alaska). Nepal (2003) find out that trails are more degraded at higher altitude, on steep gradients and there is strong correlation between high levels of trail degradation and higher frequencies of visitors. Nepal and Nepal (2004) found strong correlation between visitor use and trail degradation. However, locational and environmental factors are equally important variables. The study concludes that more systematic, and experimental studies are needed that can make a clear distinction between human-induced trail damage and the effects of natural factors. Trail grade and trail slope

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alignment angle, which often impact trail width and soil loss, were the two most important inventory indicators (Dissmeyer and Foster, 1984; Aust et al., 2004) assessed in our survey. Trails located in flatter terrain can be susceptible to widening and muddiness problems due to drainage issues. Fall-aligned trails are of particular concern for their erosivity. The trail alignment seems to be more influential on soil loss than the visitor use type (e.g. horse vs. hiker traffic) and number of users. It was assumed, that soil loss increases exponentially with trail grade, though the natural rockiness of RMNP's trail treads and stonework in our case probably limit erosion and help sustain steeper trail sections. Soil loss, attributable to several causal factors, was assessed for the trails using three measures: mean trail depth (7.1 cm), maximum incision (19.0 cm) and cross-sectional area (444.5 cm^2). Relational analyses for soil loss revealed that level of trail use and trail grade had the most influence, however dependence with trail slope alignment angle was not significant as other studies found (e.g. Wimpey and Marion, 2010). Ólafsdóttir and Runnström (2013) discovered that of the analyzed physical properties only elevation has a clear relationship with hiking trail condition in both study sites. Severe conditions never apply to a whole trail, suggesting that trail conditions are a function of trampling magnitude and local physical properties. Hence, when maintaining hiking trails in vulnerable environments, a holistic understanding of the environmental impact of trampling is critical.

When comparing two types of recreational visitor use (hikers and horseback riders), our results indicated that medians were greater for trail width, maximum incisions and soil loss in case of trails that allowed horseback riders. This shows that horse use within the park generally increases impacts to the trail system when looking at specific indicators in specific locations. It is compatible with results of other studies. Pack animals according Barros and Pickering (2015) caused more damage than hikers to the alpine meadow and their impacts were apparent at a lower level of use than for hikers. Horse traffic also consistently made more sediment available for erosion from llama, hiker or no traffic (Deluca at al., 1998). It is important to notice that horse riding trails can have

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plant species, many of which did not grow naturally in the forest and they may in long run change the structure of communities (Törn et al., 2009).

Fall-aligned trails with higher grades frequently require significant investments in rockwork and ongoing maintenance to keep them sustainable (esp. after activity of water and freezing winter temperatures). Trail width can also be influenced by many other variables including use level, visitor behavior, trail grade, landform grade, trail ruggedness, and trail borders. Some authors (Wimpey and Marion, 2010) found the relationship of trail width was most associated with trail and landform grade and trail slope alignment due to restriction lateral dispersion of hikers on steeper grades. Our results confirm that trail width is predominantly a function of use level. Mean trail width is a relatively wide 89.9 cm, though many trails are purposefully designed with wider widths to support heavy visitor use. Trail width difference with a mean of 22.6 cm is indicating that the formal trails are generally wider than intended. Other important factors we found were the behavior of visitors and absence of trail borders. Trails without borders will lead to further widening since visitors have a hard time discerning where the trail is located. The ruggedness of a trails' tread can also encourage the widening of trails since hikers often looking for easier passage to avoid these areas which are often along trail sides. To address these issues managers can manipulate the level of trail use, create trail boarders or educate visitors how to decrease their impact on trails. These solutions are easily implemented and relatively cost effective. An obvious solution for managers to prevent soil loss would be to control use levels, though this is often not popular with visitors and does not act as part of the parks mission to allow access. A second option would be to relocate trails located in areas highly prone to soil loss. Wilderness values may inhibit relocations of trails so this might be an option that could be used only in select locations (excessively steep or aligned closely to the fall line). A third option is to shorten the time between regular maintenance visits for each trail (Birchard and Proudman, 2000). This option would likely be the least economic and have impacts to visitation and wilderness due the more frequent presence of workers or closures of trails for work. Some authors commonly recommend to prevent soil loss keeping grades of less than 10–12 % (Hooper, 1988; Hesselbarth et al., 2007), trail slope alignment higher than 22° (Olive and Marion, 2009) and trail slope ratio less than 0.5 (IMBA, 2004). Our survey found that 24 % of the evaluated trails exceed a grade of 15 %. Additionally, only 6 % of the evaluated trails are aligned within 22° of the fall line, which greatly impedes management efforts to remove water from incised treads. Soil erosion would be much higher than assessed were it not for the substantial amount of granitic rock in the soils and the extensive use of rock steps – see also Fig. 2. As Moore et al. (2012) stated trail impacts are perceived by visitors and have an overall negative effect on user experiences, so it has potential implications for trail design and maintenance priorities. Ballantyne et al. (2014) recommended that management should seek to minimize the creation of informal trails by hardening popular routes and centralizing visitor flow. Different walking track types can have an effect on different vegetation characteristics (Hill and Pickering, 2006). In some cases closure of recreational sites and trails can be a solution, however longer time is effective in improving most of the soil properties in the topsoil (Özcan et al., 2013). The importance of tolerant vegetation communities to damage by trampling is indicated by resistance, as well as resilience (Pickering and Growcock, 2009). Restoration of damage to natural vegetation and soils by human use in alpine environments can have limited success due to severity of the environment which restricts plant growth and increase potential for soil erosion (Scherrer and Pickering, 2006).

Regarding methods distance-based technique in which measurements are made at regular spatial intervals is quite time consuming. Sampling at 20 m intervals technique can be used to assess typically 5–7 km of track per day in remote areas (Hawes et al., 2006). Our experiences confirmed time consumption so there will be fair discussion about practicality to repeat these measurements as a part of potential monitoring program. Combination with GIS-based methodologies could be more effective tool (Hawes et al., 2013; Ballantyne et al., 2014; Ólafsdóttir and Runnström, 2013) to examine the relationship between trail condition assessment and local physical properties, such as elevation, gradient, soil type, and vegetation cover. For further trail monitoring a recommendation to consider is the possibility to increase precision of measurements (sub-meter accuracy GPS units, smaller intervals for measurements between sampling points 30 m – this will increase time capacity). LiDAR derived terrain models could greatly speed up collection of measurements. Maximum incision and trail width are the most significant predictors of CSA which can be used for simplifying during measurements. The lack of precise measurements, especially for CSA and trail boundary determinations (historic vs. recent erosion), could be influenced. Any previous work on the trail could have also impacted the precision of measurements. Previous side hill work indicated places where trails where manually improved so the original methodology considered for final estimation of soil loss at these points were points with no soil loss. It is also important to add presence of trail border into point sampling from what can be used for analysis, especially with the trail width indicator. Contrary to the original methodology for simplification, we slightly modified categories of trail surface.

6 Conclusions

Land managers are faced with how to reduce impacts to trails from increased visitation while balancing budget and policies with political and social values. Trail maintenance can be quite costly and full closure of trails is unpopular with the public and sometimes goes against the park's mission of "freest recreational use" meaning creative solutions are needed. For example, once a fall-aligned trail becomes incised, water trapped on the tread is exceptionally difficult to direct off and can substantially increase its potential for erosion. Using the natural rockiness of RMNP's trail treads and stonework can limit erosion and meet wilderness values. In flatter terrain, such trail alignments are susceptible to muddiness and widening. Fall-aligned trails with higher grades frequently require significant investments in rockwork and ongoing maintenance to keep them sustainable. In the case of RMNP using in situ material is ideal since it has substantial amounts of granitic rock and granules present in most soils. This soil type tends to be well drained preventing muddiness. Other options include effectively using boardwalks

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or gravel based trail tread in moist locations with wet organic soils to keep tramping and compaction to a minimum. Water can drain under or over such work, though freezing winter temperatures can increase danger to trail users or harm and loosen the rock-work. In the future, precipitation is expected to become more variable producing years with high rates of runoff causing increased impacts to trails. Use of check dams or other water diversion techniques to reduce surface flow down steep trails could be pertinent. Using more clay based trail treads may also hold soils in place and reduce erosion.

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Table 1. Indicators summarized by trails (use levels: L = low, M = medium, H = high; use types: F = foot, A = all hikers + horse riders).

	Inventory Indicators									
Trail section	Length	Sample count	Elevation (m a.s.l.)	Trail grade (%)	Landform grade (%)	Slope Alignment Angle (°)	Use Levels	Use Types	Slope Ratio (%)	Rugocity (cm)
	km	*N*	Mean	Mean	Mean	Mean			Mean	Mean
Ute Trail West	6.55	43	3477	8	23	67	M	F	0.42	2.74
Boulder Field Trail	8.90	57	3458	9	19	53	H	A	0.53	3.05
Flattop Mountain Trail	5.78	36	3417	13	20	56	H	A	0.64	2.97
Mount Ida Trail	8.13	46	3657	13	27	63	L–M	F	0.57	2.90
The Saddle Trail	11.84	76	3220	12	20	53	L–M	A	0.65	2.36
Thunder Lake Trail	7.63	50	3171	13	25	54	L–M	A	0.80	2,39
Ute Trail East	6.60	53	3218	12	21	50	L	F	0.56	3.00
Trail System Mean	7.92		3374	11	22	56			0.60	2.77
Standard Deviation	2.03		177	9	12	20			0.86	0
Old Fire Trail	1.42	48	2932	12	22	55	H	F	0.53	2.16

Table 1. Continued.

Trail section	Impact Indicators			
	Trail Width (cm)	Width Difference (cm)	CSA (cm^2)	Maximum Incision (cm)
	Mean	Mean	Mean	Mean
Ute Trail West	100.58	54.86	452	7.19
Boulder Field	115.32	23.88	671	8.64
Flattop Mountain Trail	115.37	23.93	606	8.41
Mount Ida Trail	56.26	10.54	297	6.78
The Saddle Trail	90.91	15.11	387	6.27
Thunder Lake Trail	82.50	11,18	342	6.17
Ute Trail East	71.50	25.78	394	7.32
Trail System Mean	90.35	23.61	450	7.25
Standard Deviation	20.47	14.04	129	0.89
Old Fire Trail	76.15	30.43	290	5.54

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Table 2. Trail Grade (mean = 11.4 %; median = 9 %; range = 0–100 %); Trail Slope Alignment (mean = 55.9°; median = 60°; range = 0–90°); Elevation (mean = 3356.7 m a.s.l.; median = 3385.4 m a.s.l.; range = 2743–3962 m a.s.l.).

Grade	Number of sample points	Totals
0–2 %	46	12.74 %
2–6 %	78	21.61 %
6–10 %	83	22.99 %
10–15 %	67	18.56 %
15–20 %	38	10.53 %
20–30 %	31	8.59 %
30–100 %	18	4.99 %
Totals	361	100 %
Slope Alignment	**Number of sample points**	**Totals**
0–22°	23	6.37 %
22–45°	92	25.48 %
45–68°	118	32.69 %
68–90°	128	35.46 %
Totals	361	100 %
Elevation	**Number of sample points**	**Totals**
2743–2896 m a.s.l. (lodgepole pine)	22	6.09 %
2896–3505 m a.s.l. (spruce/fir)	209	57.89 %
3505–3962 m a.s.l. (alpine tundra)	130	36.01 %
Totals	361	100 %

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Table 3. Number and percent of sample points by impact indicator category.

Indicator	Sample points	Percentage
Trail Width (cm)		
0–61	75	20.78 %
61–91	128	35.46 %
91–122	108	29.92 %
122–152	39	10.80 %
152+	11	3.05 %
Mean = 89.9; median = 88.9; range = 0–193		
Trail Width Difference (cm)		
−76 to −15	15	4.16 %
−15–+15	143	39.61 %
+15–+76	190	52.63 %
+76–+152	13	3.60 %
Mean = 22.6; median = 20.3; range = −45– + 147		
Maximum Incision (cm)		
0	3	0.83 %
0–1.3	1	0.28 %
1.3–2.5	16	4.43 %
2.5–7.6	209	57.89 %
7.6–12.7	107	29.64 %
12.7+	25	6.93 %
Mean = 7.1; median = 6.3; range = 0–19		
CSA Soil Loss (cm^2)		
0	3	0.83
0–645	291	80.61
645–1290	61	16.90
1290+	6	1.66
Mean = 444.5; median = 387; range = 0–1509.6		
Mean Trail Depth (cm)		
0	3	0.83 %
0.0–1.3	7	1.94 %
1.3–2.5	76	21.05 %
2.5–7.6	251	69.53 %
7.6–12.7	23	6.37 %
12.7+	1	0.28 %
Mean = 4.1; median = 3.8; range = 0–12.9		

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Table 4. Summary statistics of tread width (TW), tread width difference (DIF), maximum incision (MIC) and soil loss (CSA) by use level.

	Use Level	TW	DIF	MIC	CSA
Low	N	141	141	141	141
	Mean	63.5	17.8	6.65	316.1
	Median	63.5	17.8	5.71	251.6
	SD	21.6	21.6	3.48	223.8
	Minimum	0	−45.7	0.00	0
	Maximum	127	81.3	19.05	1051.6
Middle	N	127	127	127	127
	Mean	101.6	27.9	6.76	445.2
	Median	96.5	20.3	6.35	393.5
	SD	26.9	33.8	2.97	242.6
	Minimum	35.6	−25.4	1.90	90.3
	Maximum	193.0	147.3	17.78	1509.7
High	N	93	93	93	93
	Mean	114.3	22.9	8.56	645.2
	Median	114.3	22.9	7.62	574.2
	SD	19.8	19.8	3.20	285.8
	Minimum	78.7	−12.7	3.17	251.6
	Maximum	162.6	71.1	17.14	1490.3

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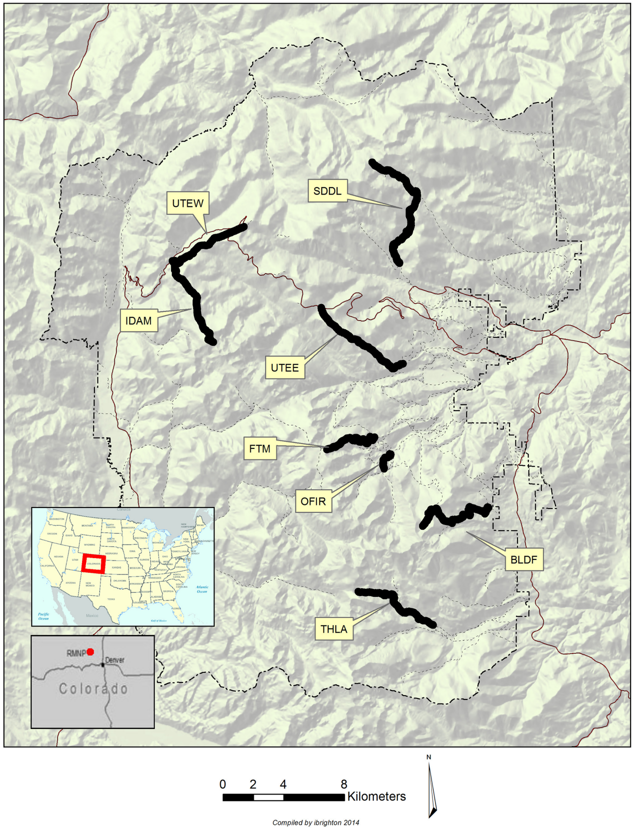

Figure 1. Study area showing all eight evaluated trails – abbreviations of the names of trails: Saddle (SDLL), Ute West (UTEW), Mount Ida (IDAM), Ute East (UTEE), Flattop Mountain (FLTM), Old Fire (OFIR), Boulder Field (BLDF) and Thunder Lake (THLA).

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Use of natural materials to limit the trail can prevent it from widening and formation of secondary trails - Boulder Field Trail.


Change of tread substrate characteristics is connected also with elevation – in the forest zone are more commonly found exposed tree roots - Flattop Mountain Trail.


The highest sections of Mount Ida Trail are barely recognizable due to very small visitation.


Old Fire Trail is an example of social trail with high traffic, some sections were in past maintained.


One of the typical examples how orientation and slope of trail have impact on the width of the trail – Saddle Trail.


Thunder Lake Trail is used by hikers and stock as well – one of the effects is expansion of the width and depth of the trail with the consequent loss of soil.


Ute East Trail – problem with erosion is notable particularly in section down from Timberline Pass.


Secondary treads are more common in areas with lower grade - Ute West Trail.

Figure 2. Photographs from all evaluated trails.

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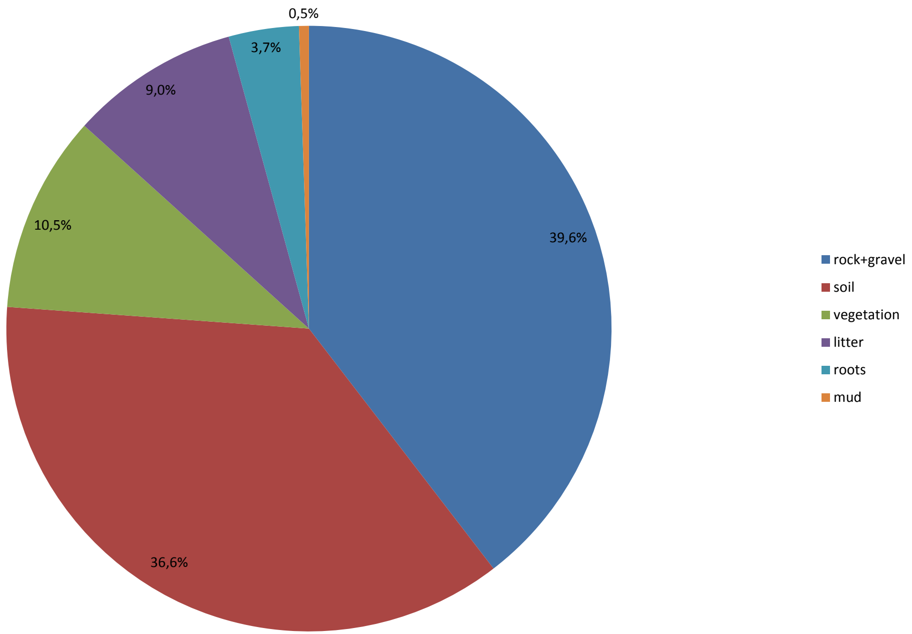

Figure 3. Mean trail substrate cover as a proportion of transect (tread) width.

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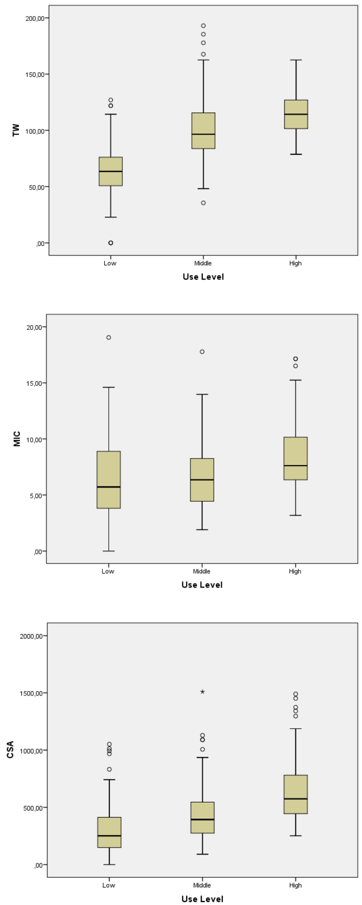

Figure 4. Boxplots of trail width (TW), soil loss (CSA) and maximum incision (MIC) values for three levels of trail use.

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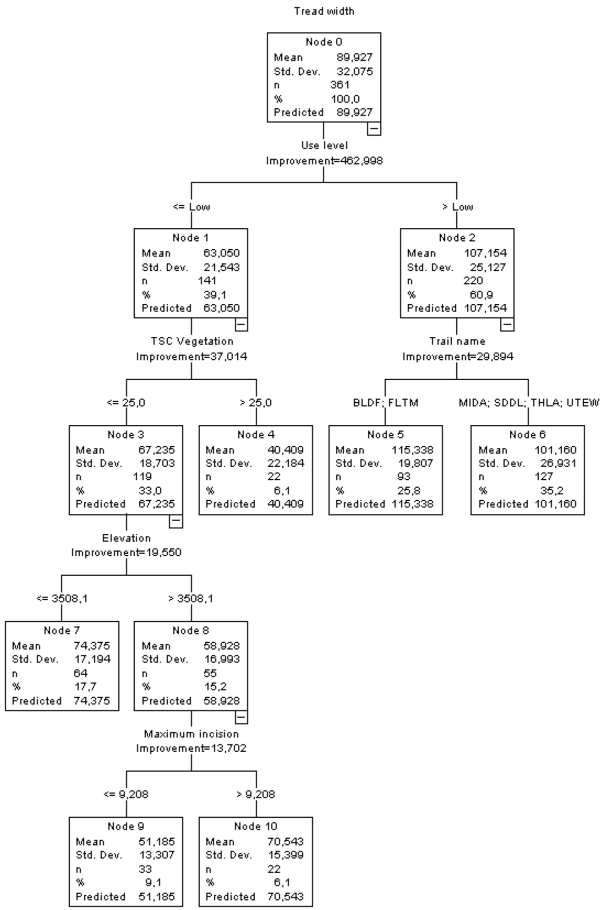

Figure 5. CRT regression tree of tread width.

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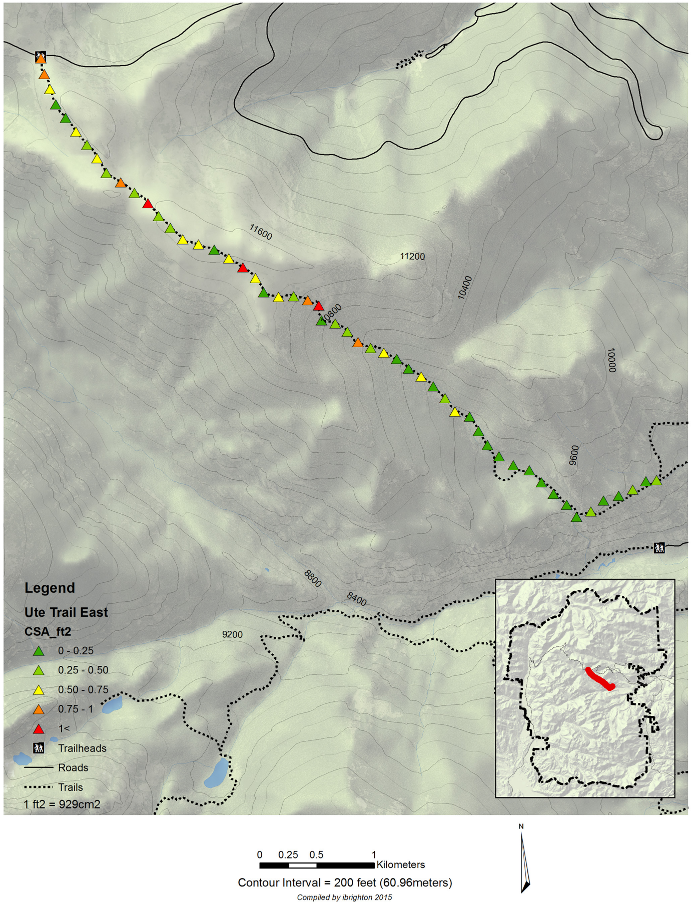

Figure 6. Example of soil loss volume on evaluated trails indicated to managers the worst points.

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