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Research article

Assessing the influence of sustainable trail design and maintenance on soil loss

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A R T I C L E I N F O

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A B S T R A C T

Natural-surfaced trail systems are an important infrastructure component providing a means for accessing remote protected natural area destinations. The condition and usability of trails is a critical concern of land managers charged with providing recreational access while preserving natural conditions, and to visitors seeking high quality recreational opportunities and experiences. While an adequate number of trail management publications provide prescriptive guidance for designing, constructing, and maintaining natural-surfaced trails, surprisingly little research has been directed at providing a scientific basis for this guidance. Results from a review of the literature and three scientific studies are presented to model and clarify the influence of factors that substantially influence trail soil loss and that can be manipulated by trail professionals to sustain high traffic while minimizing soil loss over time. Key factors include trail grade, slope alignment angle, tread drainage features, and the amount of rock in tread substrates. A new Trail Sustainability Rating is developed and offered as a tool for evaluating or improving the sustainability of existing or new trails.

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1. Introduction

Achieving conservation objectives in protected natural areas requires the ability to sustain visitation while avoiding or minimizing adverse environmental impacts. While roads provide visitor access to protected natural areas, trails are often the predominant means of access within protected areas. Some trails, such as the Appalachian National Scenic Trail in the U.S., the Via Alpina and Grand Randonnée 20 trails in Europe, and the Overland Track in Australia, are themselves a primary attraction feature that draws visitation to protected natural areas. Trails are an essential infrastructure component that can minimize resource impacts by concentrating traffic on hardened treads sustainably designed and maintained to limit the areal extent and severity of resource impact. In this paper we define a sustainably designed trail as one that limits both trail degradation and annual maintenance while accommodating its intended amount and type of use.

Concentrated traffic from hikers, backpackers, mountain bikers, and horse riders on natural surfaced trails removes or prevents the establishment of vegetative and organic litter cover on treads, compacts substrates, and increases water runoff and the erosion of soil (Hammitt et al., 2015; Marion et al., 2016; Whinam and Chilcott, 2003; Wilson and Seney, 1994). Trails in flat terrain can also suffer from trail widening, braiding, and muddiness (Leung and Marion, 1996; Wimpey and Marion, 2010). From a conservation perspective, the loss of soil is perhaps the most significant form of environmental impact because it is long-term or irreversible without substantial management action, and eroded soil can enter waterways, causing secondary impacts to aquatic environments (Marion et al., 2016; Olive and Marion, 2009). The rutting, exposed roots and rocks, and tread roughness caused by soil loss also: 1) increases the difficulty of hiking or riding, 2) diminishes aesthetic qualities, 3) impedes maintenance efforts to remove water from incised treads, and 4) contributes to trail widening, expanding the total area of disturbance associated with trail networks, (Marion et al., 2016). While some of these environmental impacts are unavoidable, excessive impacts threaten resource protection values, visitor safety, and the quality of recreational experiences.

Trail degradation, particularly soil loss, is a complex process. Soil scientists have developed a number of soil erosion models for agricultural settings, beginning with the universal soil loss equation (USLE) and later improved as the RUSLE (Kirkby, 1980; Renard et al., 1997). The models predict average annual soil loss based on six factors, including soil erodibility, rainfall erosivity, topography

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(slope length and steepness), cover management, and support practice. These models and others (e.g., the Water Erosion Prediction Project for forest roads, WEPP_Road) have been adapted and applied to forest roads (Croke and Nethery, 2006; Rhee et al., 2004; Wade et al., 2012), and even to unsurfaced trails (Aust et al., 2004; Kidd et al., 2014). However, these models have not been validated for trails, which have substantially different watersheds and uses than agricultural settings and forest roads.

Recreation ecology studies have also investigated numerous factors that influence trail soil loss, including use-related factors such as the amount, type, and behavior of trail users, environmental factors such as soil and vegetation abundance and type, and managerial factors such as trail design, construction, maintenance, and visitor use regulation and education programs (Leung and Marion, 1996, 2000; Newsome et al., 2001; Olive and Marion, 2009; Ramos-Scharrón et al., 2014). Much of the existing research has focused predominantly on use-related and environmental factors (Farrell and Marion, 2002; Hammitt et al., 2015). Few studies have investigated the influence of managerial actions, though they have considerable potential for modifying the roles of use-related and environmental factors (Leung and Marion, 1996; Marion and Leung, 2004; Marion, 2016). Among managerial factors, research attention has focused on design attributes, primarily trail grade, and less frequently on trail slope alignment, tread drainage, and tread surfacing (Olive and Marion, 2009). For example, we found only two studies that evaluated the effectiveness of alternative tread drainage actions on soil loss (Marion, 1994; Grab and Kalibbala, 2008).

Sustainable trails are designed, constructed, and managed to accommodate their intended types, amounts, and seasons of use to provide high quality visitor experiences while protecting the trail infrastructure and adjacent natural resources. Existing research suggests that trail design, a trail's siting and alignment relative to topography and soils, is the most important factor influencing long-term sustainability (Marion, 2016; Marion et al., 2011; Olive and Marion, 2009; Ramos-Scharrón et al., 2014). Poorly designed trails deteriorate quickly under traffic, unnecessarily degrade the local environment, and are more difficult to use and manage, requiring substantially greater maintenance effort (Marion and Leung, 2004). Such trails are unsustainable unless extensively hardened, or tread degradation is likely to be severe and unacceptable.

This paper investigates the influence of selected managerial factors on trail soil loss through regression modeling and analyses of trail datasets from research conducted at the Hoosier National Forest (Indiana), Big South Fork National River and Recreational Area (Tennessee), and Acadia National Park (Maine). Data from these protected natural areas are used to evaluate similarities and differences in findings and to gain improved insights from different environmental settings and trail design and management practices.

2. Literature review

This review focuses on several managerial factors pertaining to the design and maintenance of sustainable trails, including trail grade, trail slope alignment angle, trail drainage, and trail substrates.

2.1. Trail grade and slope alignment

The slope or grade of a trail and its alignment relative to local topography are determined when it is laid out or created by visitor use, hence our inclusion of these attributes as managerial factors. Numerous studies have examined the influence of trail grade on tread soil loss and found a strong positive relationship (Farrell and Marion, 2002; Helgath, 1975; Olive and Marion, 2009). The authors note that statistical modeling by Dissmeyer and Foster (1984) reveals that soil erosion rates become exponentially greater with increasing trail grades, particularly above 10%. These findings can be explained by the greater velocity and erosivity of running water on steep slopes as shown in soil erosion models (Renard et al., 1997), and by increased slippage or gouging of feet, wheels, and hooves that displace soil down-hill (IMBA, 2007; Leung and Marion, 1996).

Numerous trail maintenance books offer guidance regarding maximum trail grades to minimize soil loss on trails, though none appear to be based on empirical data from scientific studies. We believe this to be a significant limitation in our current literature which highlights the need for an expanded program of trail science research. Some recommended maximum trail grades are 10% (Hooper, 1988), 12% (Agate, 1996; Hesselbarth et al., 2007; National Park Service, 2007), and for horse trails 9% (Vogel, 1982), 10% (Wood, 2007), and 5–12% (Hancock et al., 2007). These values are generally applicable for medium-textured soil substrates; many authors suggest steeper grades are acceptable over short distances, particularly if they have sufficient native or applied rock to deter tread displacement and erosion. Regression modeling by Olive and Marion (2009) found trail grade to significantly influence soil loss, with substantially greater soil loss at grades above 11%.

Parker (2004) provides guidance on maximum permissible tread lengths between trail dips and crests based on trail grade and substrate texture, though empirical data are not cited as a basis. The IMBA (2007) suggests a maximum sustainable grade as low as 5% for sandy/fragile soils, 10% for loamy/mixed textures, and 15% for rocky or durable soils. Again, no empirical data are cited as a basis for this guidance. This reference and the widely cited Trail Solutions book (IMBA, 2004) highlight the need to consider an array of variables in determining maximum sustainable grades, including trail alignment relative to landform slope (discussed below), frequency of grade reversals (tread lengths), soil and vegetation type, and type or number of trail users and trail difficulty.

IMBA (2004, 2007) promotes the “10% Average Guideline,” which suggest that trails with an average or overall grade of 10% or less will generally be sustainable with respect to soil loss. The average grade is calculated by summing elevation gain for sections of the trail that are consistently climbing, dividing by trail length, and multiplying by 100. This guidance can be difficult and/or inaccurate to apply when a trail alternately ascends and descends or when exceptionally steep trail grades are offset by large portions with low grades. Such guidance is most easily applied when comparing alternative trail alignments on topographic maps or with Geographic Information System (GIS) software; application in the field with clinometers, tape measures, and flagging tape presents greater difficulty.

A trail design factor that receives considerably less attention by trail professionals and scientists is what Leung and Marion (1996) term trail slope alignment angle (TSA). This indicator is more easily assessed with a compass as the smallest difference in bearings between the prevailing landform slope (aspect) and the trail's alignment. The TSA of a contour-aligned trail would equal 90°, while a “fall-line” trail (aligned congruent to the landform slope or direction followed by water drainage) would have a TSA of 0°. Trail alignments with low TSA's more directly ascend slopes and their adjacent side-slopes are relatively flat in reference to the plane of the trail tread (Fig. 1). Such alignments are highly susceptible to degradation because initial traffic displaces or compacts soil, incising the tread, which then transports water that contributes to erosion in sloping terrain and muddiness in flat terrain (Basch et al., 2007; Olive and Marion, 2009; Wimpey and Marion, 2010). Tread water drainage features are difficult or impossible to install and are