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Research article

Comparison of trailside degradation across a gradient of trail use in the Sonoran Desert

Helen Ivy Rowe [a, *], Melanie Tluczek [a], Jennifer Broatch [b], Dan Gruber [a], Steve Jones [a], Debbie Langenfeld [a], Peggy McNamara [a], Leona Weinstein [a]

[a] McDowell Sonoran Conservancy, Scottsdale, AZ, USA
[b] School of Mathematical and Natural Sciences, Arizona State University at the West Campus, Glendale, AZ, USA

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ABSTRACT

As recreational visitation to the Sonoran Desert increases, the concern of scientists, managers and advocates who manage its natural resources deepens. Although many studies have been conducted on trampling of undisturbed vegetation and the effects of trails on adjacent plant and soil communities, little such research has been conducted in the arid southwest. We sampled nine 450-m trail segments with different visitation levels in Scottsdale's McDowell Sonoran Preserve over three years to understand the effects of visitation on soil erosion, trailside soil crusts and plant communities. Soil crust was reduced by 27–34% near medium and high use trails (an estimated peak rate of 13–70 visitors per hour) compared with control plots, but there was less than 1% reduction near low use trails (peak rate of two to four visitors per hour). We did not detect soil erosion in the center 80% of the trampled area of any of the trails. The number of perennial plant species dropped by less than one plant species on average, but perennial plant cover decreased by 7.5% in trailside plots compared with control plots 6 m off-trail. At the current levels of visitation, the primary management focus should be keeping people on the originally constructed trail tread surface to reduce impact to adjacent soil crusts.

1. Introduction

An estimated 78.3 million adults visited trails in the United States in 2008 and that number is predicted to increase 30% by 2030 (White et al., 2014). One early comprehensive review estimated that trails and campsites together disturb only 1% of the total area of wilderness (Cole, 1987), but this was based on estimates of area rather than direct experiments on the effects of disturbance on ecological function (Adkinson and Jackson, 1996). The concern over visitor disturbance in natural areas has motivated extensive research on trail impacts, as seen by multiple review papers over the years (Ballantyne and Pickering, 2015; Cole, 1987; Hammitt and Cole, 1998; Kuss et al., 1990; Leung and Marion, 2000; Monz et al., 2013), and more recently, in research studying the effects of trails on surrounding ecological communities (as reviewed by Monz et al., 2013). Trail impact studies generally focus either on: a) examining the changes along established trails and around campsites, or b) testing resistance and resilience of undisturbed areas through controlled trampling in undisturbed areas (Monz et al., 2013).

On established trails, disturbance occurs initially at the time of trail construction as a result of opening canopies by vegetation removal, compaction of soil and alteration of drainage patterns by removal of upper soil horizons, and modification of micro topography, affecting microclimate (Cole, 1987). Subsequently, ongoing trail visitation has direct (trampling) and indirect effects (compacted soils, reduced organic matter and reduced soil nutrient changes) on trailside vegetation (Monz et al., 2010). As demand for recreational trails and trail use continues to grow, understanding anthropogenic environmental impacts will become increasingly important to inform sustainable resource management.

The Sonoran Desert is a prime destination for outdoor recreation. For example, Scottsdale's 13,000 ha McDowell Sonoran Preserve (MSP), which is the largest urban preserve in the United States, received 750,000 visits in 2016, yet it is only one of many natural areas surrounding the Phoenix metropolitan area. Since environmental factors such as climate and geology, and the intermediate elements of topography, soil, and vegetation type

* Corresponding author.
E-mail address: helen@mcdowellsonoran.org (H.I. Rowe).

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significantly affect the degree and type of trail degradation (Leung and Marion, 1996), each ecological system responds differently to trail visitation and associated impacts. In a recent review of 59 original research papers on trail impacts, over 50% of the papers focused on just three habitat types: temperate forests, alpine and montane grasslands and shrublands, and Mediterranean forests, woodlands and sclerophyll scrub, while only 2 papers (3%) focused on deserts and xeric shrublands (Ballantyne and Pickering, 2015), and these latter papers were either focused on the impacts of roads (Brooks and Lair, 2005), or on the effects of vehicles or pedestrian use on untrampled dune systems (Rickard et al., 1994).

Soil crust is a key biological indicator of disturbance in southwest arid environments (Allen, 2009; Belnap, 1998). In the southwest and similar environments, biological soil crust plays an important role in increasing soil stability, water infiltration, and soil fertility in otherwise erodible, dry, and infertile soils (Belnap, 1994; Belnap and Gardner, 1993; Harper and Marble, 1988; Johansen, 1993; Metting, 1991; Williams et al., 1995). Consequently, soil crust loss can result in soil erosion and loss of soil nutrients (Belnap and Gillette, 1997; Harper and Marble, 1988; Schimel et al., 1985). Soil crusts are likely susceptible to trail impacts because they are brittle when dry and crush easily with trampling (Belnap and Gardner, 1993).

In our informal review of over 75 related papers, none of the trail impact studies in arid regions studied effects across a gradient of use levels. Studies in other regions which did measure impact as a function of use levels produced a variety of results (Ballantyne and Pickering, 2015). Most trampling studies reported a definite, often curvilinear or asymptotic, positive relationship between increased use intensity and increased physical and biological impacts (Andrés-Abellán et al., 2006; Ballantyne and Pickering, 2015; Boucher et al., 1991; Wimpey and Marion, 2010), but others found no clear relationship with use levels (Nepal and Way, 2007) or that plant cover increased closer to trails, regardless of use intensity (Bright, 1986; Hall and Kuss, 1989). Some studies found that other factors—visitor behavior, type of use (equestrian, bicycle, pedestrian), floristic community, topography, and others— appeared to be more important than use levels in causing physical and biological impacts (Adkinson and Jackson, 1996; D'Antonio et al., 2016; Dixon et al., 2004).

Recreation activities can cause impacts to soil, vegetation, wildlife, and water (Leung and Marion, 1996), yet principles of sustainable natural resource management include preserving biological diversity and providing safe, enjoyable experiences for visitors. In order to balance these objectives in a given ecological system, it is critical to understand how increased use affects biodiversity. We investigated the resilience of trailside vegetation and soil crusts to different visitation levels in the Sonoran Desert. Thus, we had two objectives for our study: 1) to evaluate trail impacts on vegetation and soil crusts, and 2) investigate whether these impacts are affected by different levels of trail visitation in the Sonoran Desert.

2. Methods

2.1. Sites

The MSP is comprised of Sonoran Desert Upland habitat (Brown et al., 1979) which lies at the northeastern edge of the Phoenix metropolitan area in central Arizona (33.59 N, 111.76 W). Due to the proximity to the Phoenix urban core, the MSP receives heavy visitation by hikers, bikers, and equestrians. The City of Scottsdale estimates that there were approximately 750,000 individual visits in 2016. Motorized vehicles are not permitted in the MSP.

Annual temperatures ranged from 20 °C to 46.7 °C at the two nearest weather stations during the study years 2014–2016 (Flood Control District of Maricopa County, 2017). Precipitation means from the four nearest precipitation gauges indicated rainfall was above average in the years preceding the first two sampling periods of the study (27.7 cm in 2013, 26.9 cm in 2014; Table 1), and slightly below average rainfall in the year preceding the final sampling season (22.6 cm in 2015; Table 1). The Sonoran Desert climate includes two distinct rainy seasons: one in the winter (December–March), and one in the summer (June–September).

The MSP is topographically and biologically diverse, ranging in elevation from 515 to 1237 m above sea level. A biological inventory conducted between 2011 and 2013 found 368 plant species and 188 vertebrate animal species (Jones and Hull, 2014; McDowell Sonoran Conservancy, 2014). There are 14 distinct plant associations distributed across the MSP (Jones and Hull, 2014). Bedrock geology and soil types differ across the MSP, with predominantly metamorphic rock in the south and decomposed granite in the north (Skotnicki, 2016).

Three blocks were identified which contained similar attributes within each block but were distinct between blocks (Table 2). Within each block, 3 trail segments were selected to represent a gradient of trail visitation levels and to minimize differences in plant association, soils, geology, slope, and elevation within block (Table 2). A fourth control transect that had no visitation was established within each block at least 100 m from the trails.

Plant communities differed by block (Table 2). The common associated perennial plant species at the Gateway block are brittlebush (*Encelia farinosa),* barrel cactus (*Ferocactus cylindraceus*), buckhorn cholla (*Cylindropuntia acanthocarpa*), catclaw acacia (*Acacia greggii*), chain fruit cholla (*Cylindropuntia fulgida*), creosote bush (*Larrea tridentata*), and saguaro cactus (*Carnegiea gigantea*). The Tom's Thumb block shares many of the common perennial plant species with the Gateway block, but being higher elevation also contains Arizona desert −thorn (*Lycium exsertum*), Wright's buckwheat (*Eriogonum wrightii*), fairy duster (*Calliandra eriophylla*), globe mallow (*Sphaeralcea ambigua*), goldeneye (*Bahiopsis parishii*), and Mormon tea (*Ephedra aspera*). Creosote bush (*Larrea tridentata*), and saguaro cactus (*Carnegiea gigantea*) are present in lower densities than they are in the Gateway block. Trail segments within the Brown's Ranch block share the same common perennial plants as Tom's Thumb block, however, saguaros are present in greater density (Jones, 2015).

2.2. Trail visitation levels

The research objectives were met by placing paired plots adjacent and 6 m away from trails of contrasting visitation levels. Trail segments were chosen to capture low, medium and high visitation levels within the same biotic community and soil type according to estimates informed by preliminary data from mechanical and volunteer counters.

We used two approaches to quantify visitation rates during the study. First, mechanical counters (Diamond Traffic Products, Model TTC-4420) were placed at the beginning of each trail segment transect (Fig. 1) and collected data for 24 months (2014–2015). Secondly, volunteers seated next to each mechanical counter counted trail visitors for 2 h during peak visitation (7–9 a.m. in summer, 8–10 a.m. in spring and fall, and 9–11 a.m. in winter) on the third Saturday of each month for January through November 2014 and 2015 (hereafter designated as "volunteer count").

The mechanical counters provide hourly counts of visitors throughout the year. Unfortunately, the mechanical counters appeared to have numerous data inconsistencies, including 1) daytime and nighttime hours sometimes were reversed, as evidenced by visitation occurring during the night (when the MSP is