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A Comparative Study of Impacts to Mountain Bike Trails in Five Common Ecological Regions of the Southwestern U.S.

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EXECUTIVE SUMMARY: A rapid increase in mountain biking participation over the past thirty years has led to concerns about ecological impacts to recreation environments, especially trails. It is widely accepted that recreational use of natural areas inevitably results in some degree of change to resource conditions, and managers must consider the social acceptability and ecological significance of such changes in their decision making. The ecological impacts of mountain biking, however, and relationships between impacts and trail features remain poorly understood.

This study uses Common Ecological Regions (CERs) as a mapped ecological framework to guide comparative analysis of differences in maximum trail incision and trail width at varying slope levels for mountain bike trails in five CERs in the southwest U.S. A point-measurement trail assessment procedure was utilized to measure maximum incision and width for 163.2 miles of mountain bike trails. Results show a significant effect of CER on trail width and maximum incision and a significant effect of trail slope on maximum trail incision. Maximum trail width and incision were greatest in the Arizona/New Mexico Mountains region, perhaps due to environmental features such as erodable soils and sparse trailside vegetation, higher use, and/or user behavior. Maximum incision increased consistently with slope for three of five CERs.

Relative to other trail impact research, the sites assessed in this study were in similar condition to other trails on the specific parameters measured. The findings from this study reinforce results from previous research that certain impacts to mountain bike trails, especially width, are comparable or less than hiking or multiple-use trails, and significantly less than impacts to equestrian or off-highway vehicle trails.

KEYWORDS: Recreation ecology, recreation impacts, ecological impacts, impact assessment, trail management

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Mountain biking is an increasingly popular outdoor recreation activity in North America. Although use estimates vary, according to the recent National Survey on Recreation and the Environment (2003), general bicycling was the second most popular land-based recreation activity in the United States. Of those who bicycled, an estimated 45.2 million people, or nearly 21% of the American public biked on backcountry roads, trails, or cross country on a mountain bike at least once in the twelve months prior to the survey. Mountain biking provides important individual benefits (e.g., physical exercise and opportunities to experience nature), social benefits (e.g., family bonding), environmental benefits (e.g., preservation of natural areas for trails), and economic benefits (e.g., local and regional economic stimulus). Over the past two decades, technological improvements in mountain bike materials, components, and designs have facilitated dramatic increases in participation, allowing more and more people to realize the benefits of this recreation activity.

The rapid expansion of mountain biking also has led to concerns over the potential for undesirable social and ecological impacts to recreation environments. Management issues include safety of trail users, conflict, crowding, and resource degradation. The increase in mountain biking popularity thus far has outpaced efforts to understand this activity's associated impacts, leading to confusion, user conflict, and, in some cases, strict regulations for mountain biking on public lands (Edger, 1997). In some cases, managers have implemented actions such as spatial and temporal zoning, dispersal strategies, and trail closures to address concerns. Such direct management actions that limit access can be controversial and raise issues of equity. Furthermore, the lack of scientific understanding of ecological impacts on mountain bike trails limits informed decision making. A nationwide study of U.S. state park directors conducted by Schuett (1997) demonstrated the potential for uninformed management actions. Schuett found that 67% of state park directors felt that resource degradation from mountain biking was a problem in their parks, but less than 13% of the park systems had actually conducted any studies to assess the resource impacts from mountain biking. Similarly, Chavez (1993) cited studies that suggested U.S. Forest Service and U.S. National Park Service managers were concerned about resource degradation from mountain biking, but managers "could not discern whether damage was specifically because of mountain bike use" (p. 1). As Hendricks, Ramthun and Chavez (2001) noted, "Resource impacts attributable to mountain bikes have remained debatable and understudied. At this time there is not a well-developed body of research on the environmental impacts of off-road cycling" (p. 40).

It is widely accepted that recreational use of natural areas inevitably results in some degree of change to resource conditions, and managers must consider the magnitude, social acceptability, and ecological significance of such changes in their decision-making processes. In the absence of sound scientific information, however, managers may apply a precautionary principle, and choose to restrict use or take regulatory action that is based on intuition, influence from advocacy groups, and questionable studies. Clearly, further research is needed to inform the development of best management practices to support sustainable mountain biking on established and properly constructed recreation trails.

Among the key factors affecting trail impacts deserving further study are: ecological attributes, such as vegetation and soil composition; use-related factors, such as amount and timing of use; and management factors such as trail design, alignment, and slope (Hammit & Cole, 1998; Leung & Marion, 1996). Although these significant influential factors and associated impacts have been identified, there have been relatively few quantitative studies of mountain bike trail impacts published to date that serve as building blocks for establishing relationships among the variables.

Furthermore, although there has been an increasing focus on the ecosystem concept in conservation and resource management in parks and recreation areas, the field of recreation ecology to date has not adopted a standardized mapped ecological region framework for organizing and comparing the studies that are conducted. Theoretically informed mapped ecological region frameworks are useful for classifying landscapes into hierarchical spatial units that represent characteristic patterns in the biophysical environment, human activities and impacts, and social and cultural meanings associated with landscapes (McMahon et al., 2004). Such frameworks are useful for describing and interpreting status and change in landscapes. McMahon et al. summarized the use of such frameworks by resource agencies in the U.S. and Canada which had mandated landscape assessments, biodiversity analysis, environmental monitoring and assessment, and selected indicators and standards for understanding environmental stressors and responses. According to McMahon et al., "The use of regions to stratify the underlying variability in natural conditions may increase the likelihood of detecting and understanding an environmental response generated by human activities" (p. 113). As recreation impacts are known to be related to both biophysical characteristics (e.g., soil, vegetation, and topography) as well as human activity (e.g., recreation type and amount, management intervention) it seems apparent that integrating impact studies with ecological regional frameworks might be fruitful. Also, using a standardized ecological region framework may facilitate the integration of recreation impact research into the widely accepted ecosystem research, assessment, and management framework.

To address these research needs, the goals of this study are twofold: one, to propose the use of Common Ecological Regions (CERs) (McMahon et al., 2001) as a mapped ecological region framework to guide comparative recreation impact research; and two, to evaluate the relationships between two influential factors and two common trail impacts. Specifically, this study assessed differences in maximum trail incision and trail width at varying slope levels for mountain bike trails in five common ecological regions in the southwest U.S.

Trail Impacts and the Emergence of Mountain Bike Research

The study of ecological impacts, often referred to as recreation ecology, has been, and continues to be a prominent field of inquiry for researchers, land managers, and academic professionals. Cole (1987) suggested that the field of recreation ecology began over 65 years ago with Meinecke's (1928) work on recreation impacts in the California Redwood State Parks. Recreation impacts research intensified during the 1960s and early 1970s as federal land management agencies sponsored studies to improve recreation management in natural areas. According to Leung and Marion (2000), the essence of today's ecological impact research and management lies in the desire to gain knowledge and to understand relationships among key causal and influential factors and significant effects. This knowledge is necessary to prevent, mitigate, and manage resource impacts. Campsites and trails receive the most attention from recreation impact researchers, with studies taking place in both remote backcountry and semi-remote front country settings.

The primary impact to recreation resources associated with trails occurs during initial trail design and construction (Birchard & Proudman, 2000; Sun & Walsh, 1998). Although this impact has the greatest magnitude and highest ecological significance, it is widely viewed as socially acceptable as the individual, social, and economic benefits of trail-based recreation typically outweigh the associated environmental costs (Cole, 1987). Most trail impact literature and recent research is organized around environmental and visitor-related factors (Hammit & Cole, 1998; Leung & Marion, 1996). Environmental impacts can be divided into four general categories: impacts to wildlife, water, vegetation, and soil. Visitor-related factors include amount of use, type of use, and user behavior. The foundation of recreation ecology research provides a platform for examining impacts associated with mountain biking.

The unprecedented explosion in mountain biking as a trail activity was sparked in the 1970s when cyclists began modifying bikes for off-road use (Schwartz, 1994). With balloon tires, a low, flat headset, and high clearance frame, mountain bikes brought drastic changes to places like Marin County, California. Fisher describes the early days: "In the mid-'70s we had a kind of cult riding everywhere on these clunkers" (Schwartz, 1994, p. 77). In 1981, Specialized Bicycle Components produced the first off-the-rack mountain bike, the Stumpjumper, and by 1999 mountain bike sales accounted to one-half of all units sold and one-third of all gross revenue for U.S. bicycle retailers (Bicycle Retailer & Industry News, 1999). In magazine articles from the 1980s, headlines portrayed mountain bikes as "Two-Wheel Terrors" (Foote, 1987) and "Vicious Cycles?" (Coello, 1989), and questioned whether mountain biking was "Sport or Spoil-Sport?" (Staub, 1984). Sensational captions depicted the "impacts" typical of mountain biking. Below a photo of bikers maneuvering a set of switchbacks, Foote included, "On the trail: cyclists pose a threat to nature" (p. 72). Next to a photo of two parallel bike tracks, Coello added the caption, "Along the

White Rim Trail, a jeep road in Canyonlands National Park, cyclists have gouged furrows on their way to the canyon rim" (p. 52). Cessford (1995a) questioned whether tread marks were an easy target, and one wonders if Coello would have made a similar statement about footprints leading to the canyon rim. Countering these claims, Grost (1989) noted that bikes "don't eat hay, grass ... or defecate" (p. 50) and "weigh about 872 pounds less than a horse" (p. 76).

In the 1980s and 1990s researchers began serious study of the social and environmental consequences of mountain biking. Hendricks (1997) recognized that "the 1990s have seen the mountain bike controversy mature from social and environmental issues debated with anecdotal evidence in board meetings, in popular magazines and through newspaper editorials to a land management issue supported by serious inquiry and examination" (p. 3). Researchers studied mountain biker demographics, preferences, and perceptions (Antonakos, 1993; Bowker & English, 2002; Cessford, 1995b; Goeft, 2000; Hollenhorst et al., 1995; Ruff & Mellors, 1993; Symmonds et al., 2000); manager preferences and management strategies (Baker, 1990; Chavez, 1996a, 1996b; Hendricks et al., 2001; Leberman & Mason, 2000; Mason & Leberman, 2000; Moore & Barhlow, 1997; Ruddell & Hendricks, 1997; Schuett, 1997); and social conflict (Banister et al., 1992; Carothers et al., 2001; Cessford, 2002; Ramthun, 1995; Watson et al., 1991).

The ecological impacts of mountain biking, however, remained poorly understood. In fact, several researchers indicated a need for further study in this area (Cessford, 1995a, 1995b; Chavez, 1996a; Chavez et al., 1993; Goeft, 2000; Goeft & Alder, 2001; Hendricks, 1997; Jacoby, 1990; Schuett, 1997; Thurston & Reader, 2001; Wilson & Seney, 1994). The absence of concrete information was evident in the earliest publications. In an early summary of mountain biking literature, Cessford (1995a) discussed ecological impacts and presented several astute observations, though the majority of his conclusions were derived from other forms of recreation, such as hiking and off-road motorcycling. His most notable inference was that mountain bikes will generate the most torque during uphill travel, but considerably less pressure on the trail in comparison to other users when moving downhill, although degradation is possible "in extremely wet conditions, on uncompacted surfaces, or due to poor braking practices" (p. 9). Cessford also admitted that the research available at that time could not reliably discern whether mountain biking was any more or less impacting than hiking, a sentiment shared by Ruff and Mellors (1993).

At the time of Cessford's (1995a) literature review, few physical impact studies included mountain biking. Wilson and Seney's (1994) quasi-experimental approach examined the effects of a mountain bike, hiker, horse, and motorcycle on runoff and sediment yield for trail sample plots in the Gallatin National Forest, Montana. The results of this analysis indicated that the four uses did not significantly alter runoff. With respect to sediment yield on pre-wetted plots, the horse and hiker dislodged more material than the motorcycle and mountain bike. On dry plots, the hiker, mountain bike, and motorcycle produced similar sediment yields, but again the horse produced highest yield. Sediment yield for each use was greater for pre-wetted plots than for dry plots. Wilson and Seney acknowledged that soil texture and slope are equally important factors as used in determining sediment yield. Another comparative quasi-experimental design was applied to mountain biking by Thurston and Reader (2001), who assessed the effects of hiking and mountain biking on vegetation loss, species loss, and soil exposure. Their most pertinent finding was that there was no significant difference between the impacts of hiking and mountain biking for the three variables.

Bjorkman's (1998) dissertation included two studies conducted in Wisconsin's forests. In the first project, Bjorkman determined that sediment yield and erosion associated with mountain biking were lower on a surface treated with a nylon/polypropylene liner and covered with a material made from recycled tires than on an untreated trail. For the second analysis, Bjorkman monitored a variety of impact variables over the first five seasons of, and 90,000 passes on, two newly opened mountain biking trails. The primary findings were: the greatest change in vegetation loss, compaction, cross sectional area and centerline depth on steep slopes, and mean trampled width occurred early in trail use; impacts were largely confined to the trail centerline; and erosion and trail width were greatest on slopes with ≥ 24 percent grade, though erosion was not significant on less steep slopes. In similar research, Goeft and Alder (2001) examined changes in soil compaction, erosion, trail width, and vegetation cover over one year on both recreation and racing trails in southwestern Australia. They noted that erosion was greatest on downhill slopes and at curves, and that erosion and compaction were strictly on-trail impacts. Off-trail vegetation impacts and changes in trail width proved insignificant, though both were most pronounced following a race. Widening was also more likely on wet soils and during the rainy season.

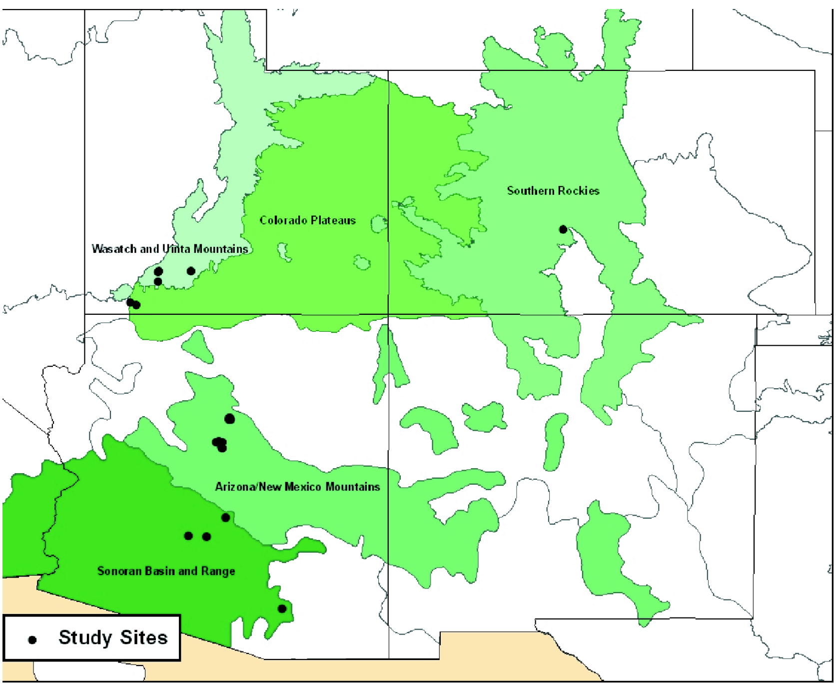
From these studies, several key points are evident. The magnitude of ecological impacts attributed to mountain biking appear to be comparable to those of hiking, and appear less than motorized trail use and equestrian use. In many cases, soil structure, slope, and environmental factors are as influential as type and amount of use in determining impacts such as soil loss. If managed properly, impacts such as compaction and vegetation loss can be confined to the trail, with minimal damage to trail peripheries. Mountain bikes have the greatest potential to damage trails in wet and muddy conditions and on steep uphill (spinning tires) and downhill slopes (skidding), which may prove problematic for managers, as many mountain bikers prefer challenging technical sections. In Bjorkman's (1998) words, "Usage has little influence in explaining impacts to the trail... The first several thousand passes create the most change whether later total use levels are 10,000 or 90,000" (p., 122). Though these limited findings acknowledge an incomplete understanding of the physical impacts of mountain biking, they do provide an early indication of conditions that may exist in the field.

Study Methods

Common Ecological Regions (CERs) Provide an Organizing Spatial Framework

This study was conducted in five common ecological regions in the southwest U.S.: Sonoran Basin and Range; Arizona/New Mexico Mountains; Colorado Plateau; Southern Rocky Mountains; and Wasatch and Uinta Mountains (see Figure 1). These ecological regions are a subset of a larger spatial framework developed through a cooperative partnership of nine U.S. federal earth science and resource management agencies. The CER spatial framework "is a mapped set of geographic regions that supports agency programs or studies" that was developed to guide cooperative ecosystem research efforts and facilitate "regionally generalized results from local investigations" (McMahon et al., 2001, p. 293-294). Thus, by using the ecological regions framework developed by the cooperating agencies, which include the Forest Service, Bureau of Land Man-

Figure 1
Map of Study Sites



agement, Fish and Wildlife Service, and National Park Service, researchers may obtain an "increased measure of confidence in moving from the results of their investigations to characterizing the region as a whole" (McMahon et al., p. 301).

The common ecological regions are based on similarities in biotic, abiotic, terrestrial, and aquatic features of the environment as well as social and cultural meanings attached to those environments (McMahon et al., 2004). These various factors were incorporated into the CERs from the amalgamation of three preliminary spatial frameworks developed by the Forest Service (USFS), Environmental Protection Agency (EPA), and National Resource Conservation Service (NRCS) (McMahon et al., 2001). Each of these three prevailing frameworks was created according to agency agendas and management directions. The latest Forest Service framework, for example, was spawned from an agency focus on ecosystem-based approach to managing national forests and grasslands. The NRCS major land resources framework was shaped from practical USDA requirements for soil classifications necessary for assessing agriculture potential and land use. The MLRA and other NRCS frameworks and soil maps work in a hierarchical manner when placed under the umbrella of the CER framework. Similar to the original USFS approach, the EPA framework is aligned with an overall ecosystem view. McMahon et al. (2001) provided a thorough review of how these three original and contributing frameworks have undergone subsequent quantitative and qualitative analysis to create the interagency coordinated CERs.

The five CERs in which data were collected for this study are characterized by vegetation, soils, physiographic, land use, land cover, and geology elements represented in the contributing frameworks mentioned above. The Sonoran Basin and Range region is characterized by extensive areas of palo verde-cactus shrub and giant saguaro cactus and has large tracts of federally managed lands. The basins are marked by grama-tobosa shrubsteppe while the ranges are covered with oak-juniper woodlands, and ponderosa pine on the higher elevations. The Arizona/New Mexico Mountains region is a relatively dry, warm environment, with chaparral at lower elevations, pinyon-juniper, and oak woodlands at lower to middle elevations, and higher elevations covered by Ponderosa pine forests and smaller areas of spruce, fir, Douglas fir, and aspen. In the Colorado Plateau region, differences in elevation distinguish this region from nearby Arizona/New Mexico Plateau where it reaches lower and Wyoming Basin to the north as it is generally more elevated. In large, low-lying areas, saltbrush-greasewood vegetation is dominant. The pinyon-juniper woodlands of the elevated plateaus of this region include sheer sidewalls of abrupt changes in local relief, ranging from 300-600 meters. The Wasatch and Uinta Mountains region, also the westernmost region in this study, encompasses a central area of high, precipitous mountains with intermittent valleys, plateaus, and open high mountains. Vegetation is manifest in a banded pattern where aspen, chaparral, and juniper-pinyon and oak are common at middle elevations. The region is also typified by less lodgepole pine and a greater emphasis on grazing livestock than in the neighboring Middle Rockies region to the north. Finally, the Southern Rockies region, which marks the eastern extent of the areas studied, includes high elevations and steep, rocky mountains. Large portions of this region are covered by coniferous forest, while the highest elevations take on alpine characteristics. Similar to the Wasatch and Uinta Mountains region, elevation banding dictates vegetation, soil, and land use in the Southern Rockies region. Lower elevations contain grasses and shrubs and are grazed heavily. Moderate elevations include grazing and are covered by Douglas fir, ponderosa pine, aspen, and juniper and oak woodlands. Higher elevations are abundant with coniferous forests that receive minimal grazing activity (US Environmental Protection Agency, 2005). Although there is variability in biotic and abiotic elements within ecological regions, this spatial framework provides a useful system for segmenting the region and providing context for interpretation and extrapolation of environmental research findings.

Trail Selection

The goal of the trail selection procedure was to identify mountain bike trails or trail segments within each ecological region that were generally typical of trail conditions in that region. A comprehensive list of potential trail segments was developed in cooperation with land management agencies and mountain bike and trail associations. The focus was to identify trail segments identified by the responsible management agency as system trails—in keeping with the purpose of the research to examine impacts to existing trails where mountain biking might be sustained as a legitimate activity. Some trail segments were initially user-created but had been adopted into the agency trail system if design parameters were within agency specifications. To isolate impacts associated with mountain bike trails to the greatest extent possible in a field research setting, trail segments were excluded from the sample frame if motorized use, equestrian use, or multiple-use was dominant. We initially planned to use a 3 x 3 x 5 full factorial design with three levels of use (low/medium/high) and three levels of slope (low/medium/high) across five ecological regions; however, once candidate trail segments were identified, the necessary diversity in use level in each region was lacking, given the use-type restrictions. Specifically, there were inadequate data points to fill cells for low use levels for four of the five CERs and medium use level for two of the five CERs. Ultimately, a total of 162.3 miles of trails were purposively selected in the five common ecological regions. Thus, several limitations of the completed sample should be noted, including the lack of diversity in use levels across the five study regions, the lack of verifiable use level information, and the small number of sample points collected in the Colorado Plateau region, which resulted from time and resource limitations for the field research data collection. Future researchers should consider collecting systematic trail use level information using trail counters or other methods.

The completed sample of trail segments in each region cannot be determined to be representative of that region and extrapolation of the study findings to the ecological region as a whole, is inappropriate at this time, and thus our findings should be cautiously interpreted at larger spatial scales. By adopting the common ecological regions as an eco-spatial framework for recreation impact research, however, we aim to encourage the long-term development of a comprehensive knowledge base of impact conditions across these regions. The CER framework is available for download as a GIS layer (US Environmental Protection Agency, 2005) and subsequent research utilizing this framework would facilitate comparative spatial analyses and ultimately confident generalizations about the relationships between specific causative and non-causative but related factors and specific impacts across different regions of the U.S., thus overcoming one of the limitations of recreation impact research—namely that research tends to be opportunistic, site-specific and driven by specific management concerns.

Trail Impact Assessment Procedures

A point-measurement trail assessment procedure was utilized in this study, focusing on measuring maximum incision and trail width. The point sampling method is most appropriate for assessing trail impacts, such as incision and width, which are continuous along the trail (Marion & Leung, 2001). For the point measurement method, a bicycle wheel measuring computer was used to identify systematic sampling points at intervals located every 805m (1/2 mile) along the trail after a random start point near the trailhead. Leung and Marion (1999) examined the influence of sampling interval on the accuracy of trail impact assessments for frequency of occurrence and lineal extent for four common impacts (tread incision, wet soil, exposed roots, multiple trailing) and found that intervals of less than 100m provided the most accurate estimate of lineal extent. Recognizing the inefficiency of such sampling intensity for most settings, however, the authors concluded that "sampling intervals between 100m-500m are therefore recommended to achieve an appropriate balance between estimate accuracy and efficiency of field work" (p. 178). Thus, a limitation of this study is a large sampling interval relative to other studies and the potential for loss in accuracy. The justification for this approach was to include as large a sample of trail miles as possible across a broad geographic region in this exploratory investigation.

At each sample point, trail boundaries were defined to include the area where the vast majority of trail use (>90%) occurred by identifying visually obvious disturbance indicated by changes in ground vegetation height, cover and composition. Temporary stakes were placed at the trail boundaries to establish a transect perpendicular to the trail tread. Trail width was defined as the distance between the trail boundary points and measured in inches to the nearest inch. A taut nylon cord was stretched between the base of the stakes and maximum trail incision (MIC) was measured as the maximum depth from the string to the trail surface in inches to the nearest quarter inch. At each measurement point, technicians used digital camera to capture site images and recorded locations using Global Positioning System (GPS) receiver. Data were collected between May 2003 and March 2005 during the primary use season for each ecological region, entered into an online Microsoft Access 2003 database and analyzed using SPSS (Version 12).

Results

Data for the study were collected from 162.3 miles of mountain bike trails across five common ecological regions, which resulted in 319 point measurements (see Table 1). Of the 162.3 miles of trails assessed, 91.7 miles were managed by the U.S. Forest Service, 27.5 miles by a county parks and recreation agency, 16.4 miles by a state government agency, 17.8 miles by the Bureau of Land Management, and 8.9 miles by a city government.

Table 1
Mileage of Mountain Bike Trails Assessed and Number of Sample Points Across Three Categories of Slope for Five Common Ecological Regions

	Mileage	Sample points			
		< 5%	5% to 10%	> 10%	Total
Colorado Plateaus	17.8	9	21	7	37
Wasatch and Uinta Mountains	26.8	16	19	19	54
Southern Rockies	29.3	15	25	12	52
Arizona / New Mexico Mountains	35.6	26	25	25	76
Sonoran Basin and Range	52.8	52	22	26	100
Total	162.3	118	112	89	319

Mountain biking was the dominant activity on all trail segments, with three trails engineered specifically for this use.

Trail slope is a key factor influencing potential for impacts to soil and vegetation on recreation trails (Goeft, 2000; Wilson & Seney, 1994) with trail slopes greater than 12% typically associated with higher potential for degradation. As shown in Table 2, 37% of the sample points had a slope of less than 5%, 35% had a slope of 5% to 10%, and 27% had a slope greater than 10%. The mean slope for all sample points in the study was 7.6% with a minimum of 0% and a maximum of 38%. Considering the trail segments in each of the CERs, the mean slopes were: Sonoran Basin and Range (7%); Arizona/New Mexico Mountains (8%); Colorado Plateau (7%); Southern Rocky Mountains (7%); Wasatch and Uinta Mountains (8%).

The mean maximum trail incision, or trail depth, across all sample points was 1.48 in. with a median of 1.0 in. and maximum 10.0 in. The

Table 2
Mean Trail Width and Maximum Incision at Three Slope Levels Across Five Common Ecological Regions

Common Ecological Region	Trail Grade	Trail Width (ft.)	MIC (in.)
Colorado Plateaus	< 5%	1.87	0.78
	5% to 10%	2.24	1.14
	> 10%	2.41	1.00
Wasatch and Uinta Mountains	< 5%	2.14	1.06
	5% to 10%	2.31	1.31
	> 10%	2.28	1.74
Southern Rockies	< 5%	1.94	1.73
	5% to 10%	2.10	2.00
	> 10%	4.02	1.67
Arizona / New Mexico Mountains	< 5%	3.45	1.62
	5% to 10%	4.12	1.88
	> 10%	2.61	2.20
Sonoran Basin and Range	< 5%	2.48	0.83
	5% to 10%	2.34	1.55
	> 10%	1.84	1.61

mean trail width across all sample points was 32 in., with a median of 26 in. and a maximum of 109 in. Table 3 displays the values for trail width and maximum trail incision by each trail slope category and across the five ecological regions. Multiple analysis of variance (MANOVA) was used to examine the relationships between the influential factors of CER and slope and the impacts of trail width and maximum trail incision. For MANOVA, the assumption is that dependent variables are multivariate normal; however analysis of variance is robust to departures from normality. The results, displayed in Table 4, showed a significant main effect of CER on both trail width and maximum trail incision. Average trail width for the sample points was significantly higher in the Arizona/New Mexico Mountains than all other regions; this was followed by Sonoran Basin and Range, Wasatch and Uinta Mountains, Southern Rocky Mountains, and Colorado Plateau. MIC was highest for the sample points in the Arizona/New Mexico

Table 3
Multiple Analysis of Variance (MANOVA) for Impact Parameters

Source	Dependent Variable	*df*	*MS*	*F*	*p*
Model	Width[a]	14	11.35	5.576	<.0005
	MIC[b]	14	4.38	4.007	<.0005
CER	Width	4	37.04	18.196	<.0005
	MIC	4	6.96	6.371	<.0005
Slope	Width	2	1.80	.885	.414
	MIC	2	4.67	4.272	.015
CER*Slope	Width	8	0.75	.371	.936
	MIC	8	0.79	.723	.671

Note. [a]R^2 = .20 (Adjusted R^2 = .17); [b]R^2 = .16 (Adjusted R^2 = .12).

Table 4
Multiple Analysis of Variance (MANOVA) for Impact Parameters

Source	Dependent Variable	df	MS	F	P
Model	Width[a]	14	11.350	5.576	.000
	MIC[b]	14	4.380	4.007	.000
CER	Width	4	37.037	18.196	.000
	MIC	4	6.964	6.371	.000
Slope	Width	2	1.802	.885	.414
	MIC	2	4.670	4.272	.015
CER*Slope	Width	8	.754	.371	.936
	MIC	8	.791	.723	.671

Note. [a]R^2 = .204 (Adjusted R Squared = .168); [b]R^2 = .156 (Adjusted R Squared = .117).

Mountains, followed by Southern Rocky Mountains, Wasatch and Uinta Mountains, Sonoran Basin and Range, and Colorado Plateau.

There was a significant main effect of trail slope on maximum trail incision—as slope increased, maximum incision increased. MIC for slopes of less than 5% was significantly lower than slopes of 5% to 10% and significantly lower than for slopes of greater than 10%. The latter two slope categories were not significantly different. There was not a significant main effect of trail slope on trail width, but, generally, as slope increased, trail width increased. Average trail width was 30 in. for slopes less than 5%, 32 in. for slopes 5% to 10%, and 34 in. for slopes greater than 10%. Figure 2 displays the findings for MIC across three categories of trail slope for each CER. For three of the five CERs—Arizona/New Mexico Mountains, Sonoran Basin and Range, and Wasatch and Uinta Mountains—incision was smallest on slopes less than 5%, higher on slopes 5% to 10%, and highest on slopes greater than 10%. In the two other regions, different patterns emerged. In the Colorado Plateaus, MIC increased from 0.78 in. at slopes less than 5% to 1.14 in. at slopes of 5% to 10%, but fell to 1.00 in. at slopes of greater than 10%. MIC for sample points in the Southern Rockies CER was 1.73 in. at less than 5% slope and increased to 2.00 in. at 5% to 10% slopes, but MIC lowest at slopes of greater than 10% (1.67 in.).

The effects of slope and CER on trail width are graphed in Figure 3. As noted earlier, slope did not have a significant effect on width for the sample points in the study, although in general higher slopes were associated with

Figure 2
Mean Maximum Trail Incision at Three Different Slope Levels Across Five Common Ecological Regions

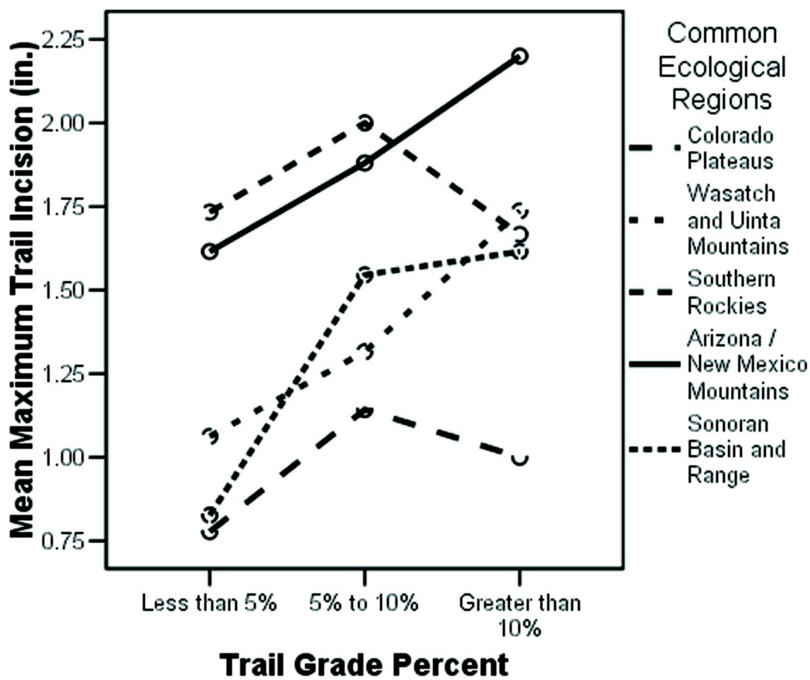
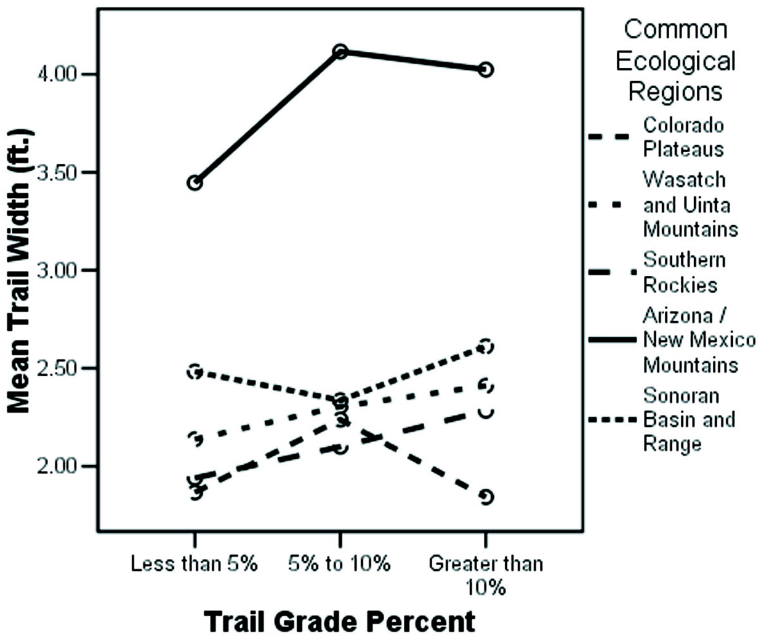


Figure 3
Mean Trail Width at Three Different Slope Levels Across Five Common Ecological Regions



higher trail width. For sample points in three of the five CERs—Arizona/New Mexico Mountains, Wasatch and Uinta Mountains, and Southern Rockies, the trend lines show higher slopes to be associated with increasing width, but the differences are small. Trail width for the sample points in the Arizona/New Mexico Mountains was significantly greater than all other regions at each slope level. In this region, width increased from 42 in. at less than 5% slope to 50 in. at 5% to 10% slopes and 48 in. at greater than 10% slope. For sample points in Colorado Plateaus, width increased from 22 in. at the lower slopes to 27 in. at the middle slopes, but then dropped to 22 in. at the steeper slopes. On the contrary, trail width for points in the Sonoran Basin and Range was lowest in the 5% to 10% slope category. The interaction between CER and slope was not significant.

Conclusions

Data for this study were collected from 319 sample points gathered from 162.3 miles of mountain bike trails in five common ecological regions of the southwest United States. Significant differences were identified between trails in different common ecological regions for both trail width and maximum incision. Trail width at sample points in the Arizona/New Mexico Mountains was significantly higher than sample points for all other regions. These finding may be explained by environmental features such as vegetation associations or soil, or by use-related variables or management factors at the specific trails included in this study. Without adequate controls, it is not possible to isolate the effects of each contributing factor, but several explanations are plausible. Environmentally, the dominant vegetation for most trail segments in the Arizona/New Mexico Mountains was sparse chapparal and pinyon-juniper and the soil was mostly sandy-loam to loam. Such relatively sparse vegetation and fine, homogenous soils may not prevent trail widening as effectively as, for instance, the imposing trailside cactus vegetation and rockier soils in the Sonoran Basin and Range or the more densely forested portions of the Southern Rockies and Wasatch and Uinta Mountains. Regarding use-related factors, the sampled trails in the Arizona/New Mexico Mountains region are located in the Coconino National Forest near Sedona and Flagstaff, Arizona and these trails were the most heavily used in the study. The trails are popular for day hiking and it is hypothesized that heavy use and user behavior contributed to increased width. For instance, although systematic observation of recreation behavior was not part of this study, field researchers' notes suggest that as mountain bikers passed others on the higher-use trails, users leave the main tread, disturbing soil and vegetation. This use-related explanation is consistent with Marion and Leung's (2001) study of trails in Great Smoky Mountains National Park, which found that trail width was the only impact condition significantly related to use level. Regarding maximum incision, values were significantly higher in the Arizona/New Mexico Mountains and Southern Rockies regions than all other regions.

Consistent with previous mountain bike trail research (Goeft & Alder, 2001; Wilson & Seney, 1994), increasing slope was associated with greater impact; in this case maximum incision. Specifically, MIC was greater at slopes of 5% to 10% than at slopes of less than 5% in all five CERs. This finding is significant, suggesting a direct relationship between slope and MIC, especially at small to moderate slopes. Future research might test this hypothesis through a multiple regression analyses to isolate the relative contribution of slope and ecological characteristics, as well as use level, and management agency. Although the interaction between CER and slope was not statistically significant, the pattern of results in the data show that MIC on sample points from two regions—Southern Rockies and Colorado Plateaus—was lower at slopes of greater than 10% than at slopes of 5% to 10%. This pattern may be explained by increased management attention to those trail segments at greater slopes, lower use on steep trail segments, or by more resistant soils. Further investigation is necessary to determine if environmental features, use-related variables, or management factors mediate the relationship between slope and incision at higher slopes. Trail slope was related to maximum incision but not trail width.

Relative to other trail impact research, the sites assessed in this study were in similar condition on the specific parameters measured. Average overall trail width for all sample points in our study was 32 in., with a median of 26 in., and average maximum incision was 1.48 in. with a range of 0 to 10 and median of 1.0 in. The width and depth of the trails in this study are similar to the multiple use trails Great Smoky Mountains National Park discussed by Marion and Leung (2001), where point sampling method found the range of width to be 9 in. to 57 in. with a median of 17 in., and a range of incision within current tread boundary of 0 in. to 6 in. and a median of 0 in. Average width in our study was similar to lower use mountain bike trails in Australia studied by Goeft and Alder (2001), which found width to range from 17 in. to 26 in., and mountain bike trails in Tennessee assessed by Marion and Olive (2004), which found average width to be 24 in. In the Marion and Olive study, average width for horse trails was 81 in. and average width on ATV trails was 104 in.; in that study, bike trails had significantly less erosion as measured by cross-sectional area, and less muddiness than horse and ATV trails as well. Similarly, Aust et al. (2005) found an average width of 82 in. for equestrian trails in Hoosier National Forest in Indiana. The findings from our study thus reinforce results from previous research that certain impacts to mountain bike trails, especially width, are comparable or less than hiking or multiple-use trails, and significantly less than impacts to equestrian or off-highway vehicle trails. Although our study focused on only two impacts, when combined with the findings of previous studies (Goeft & Alder, 2001; Wilson & Seney, 1994), a consensus seems to be emerging that recreation impacts to mountain bike trails are largely confined to the main tread and mountain biking is likely a sustainable activity on properly managed trails, at least in the environments studied thus far. To determine the sustainability of mountain biking, however, further research is warranted into other, potentially more ecologically significant impacts, such as wildlife disturbance or introduction and spread of invasive species, and across a broad range of ecological regions.

Our study does suggest that moderate to severe slopes are an area of management concern for increased incision; although we did not assess erosion (e.g., through cross sectional area), this is also a concern for moderate to severe slopes. This is potentially problematic as studies have shown that mountain bikers tend to prefer trails with steeper slopes, downhill features, and sharp curves (Cessford, 1995b; Goeft & Alder, 2001; Hollenhorst et al., 1995). For the trails in our study, the impacts were relatively modest, but systematic monitoring would be prudent. Managers may also want to clearly define and encourage a narrow trail tread in environments, such as the Arizona/New Mexico Mountains, that facilitate free travel along the trail periphery and on multiple-use trails where hikers and bikers frequently pass one another.

A final contribution of this study is the introduction of CERs as an organizing eco-spatial framework for recreation impact research. Additional studies that use this framework will facilitate comparisons of findings and ultimately allow for increased statistical power and meta-analyses to isolate the relative importance of various causal and influential factors on a wide range of impacts. Such studies, especially when using GIS analyses, have the potential to assist researchers and managers in moving from localized investigations to regionalized generalizations. Despite limitations, this study represents an exploratory first step in this progression.

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