Ecological Impacts of Mountain Biking: A Critical Literature Review

Introduction

In the post-World War II period, public interest in outdoor recreation has grown steadily. As affluence and leisure time have increased, use of public lands for recreation has risen steadily, often exceeding 10% annual growth rates through the 1960s (Knight, 1995). Today, in many areas, intensive activity by recreational users, not industrial enterprise, poses the chief challenge for land managers and activists (Knight, 1995).

In recent years, participation in some recreational pursuits has grown at a much faster rate than others. Mountain biking, in particular, has expanded rapidly. In this announcement it reported "an estimated 13.5 million mountain bicyclists visit public lands each year to enjoy the variety of trails. What was once a low use activity that was easy to manage has become more complex" (BLM, 2002). Despite this, there is currently a relative lack of scientific literature on the differential effects of mountain biking on natural systems. While the effects of recreation generally have been well studied, the extent to which mountain bicyclists affect natural systems differently remains only thinly represented in the literature (Knight, pers. comm.).

This paper will undertake a comparative review of the extant scientific literature on the impact of recreational mountain biking on ecological systems. It will then identify key areas of weakness in the literature and suggest a framework for future research.

A note on political context

This has proven to be an interesting time to write this report. The Bureau of Land Management in November finalized and released their National Mountain Bicycling Strategic Action Plan. This document will guide local land managers across the United States as they develop their approach to mountain bike recreation in their territories. In addition, California Senator Barbara Boxer has introduced a bill into the U.S. Senate (California Wild Heritage Act of 2002) that would expand California's total 14 million acres of designated wilderness by 2.7 million acres. The International Mountain Bicycling Association, now a mature, well-funded advocacy group objects to about half of the proposed new areas because they encompass current mountain biking trails. Once designated as wilderness all mechanical conveyances, including bicycles, would be banned.

As the numbers of recreational users, wilderness advocates, and industrial firms in the United States continues to increase, political controversy over America's backcountry will only intensify and become more complex. Generally, this controversy is centered on on-site conflicts between user groups (the purview of the local regime) or political conflicts between advocacy groups representing, generally speaking, certain user groups (a question of status under the 1964 Wilderness Act).

Scientific issues

Like all recreational groups, mountain bikers affect the land they use. As the numbers of mountain bikers have increased steadily and as improving technology has increased their range, these affects have increased. These impacts can be classified, broadly, into the following categories:

- "Trampling:" Defined as the mechanical destruction and mortality of ground level vegetation on undeveloped terrain (off-trail).
- "Erosion:" Defined as the mechanical mobilization of sediment. In an off-trail context, this is related to trampling. For the most part, when erosion is studied individually, it is in the context of a developed trail.
- "Wildlife disturbance:" The disruption of animal ecosystems through human presence, leading to added stress and consequent affects on populations and individuals.

Long intuitively grouped with other "ecologically friendly" users such as hikers, mountain bikes are regarded to be relatively low impact in these categories. However, there really isn't much data currently showing that mountain bikers do, in fact, impact land similarly to hikers. On the other hand, as it turns out, there is also very little data showing they don't.

Differences between bicyclists and other user groups can generally be divided into two categories:

- Behavioral
- Mechanical

The clearest if these two differences are the mechanical. A mountain bike tire, propelled by human power, would seem intuitively to exert much less erosive force on trails and vegetative cover than a motorcycle tire. However, it may inflict sufficient damage to these surfaces to be better grouped with a motorcycle than with a hiker. Further, the distance a bicyclist can travel in an hour with the advantage of modern gearing far exceeds that of a hiker. A mountain bike traveling downhill at a high speed might stress wildlife more than a hiker.

However, there may also be behavioral differences between groups. It could be that bicyclists are more (or less) likely to go off-trail, cut switchbacks, or litter in the backcountry. Mountain bicyclists may be more prone to bringing off-leash dogs that harass wildlife. This study will focus on the scientific literature as it addresses impact differences between hikers and bicyclists. To the extent that credible experimental treatment design must attempt to reflect real-world use of wilderness areas, some behavioral attributes of hikers and bikers (e.g. how fast they travel) are an important component of any study. In fact, a lack of this tends to be a weakness of all experimental designs discussed here.

Behaviors characteristic of mountain bikers but not necessarily of the bikes themselves (i.e. higher propensity to litter as opposed to speed of travel) will not be addressed in this report as they vary from location to location. For example, some areas are likely to be near a population center with riders willing to build illegal trails, while other areas may have fewer such riders. Such issues are questions for local management and enforcement; the study of them requires sociological methods.

Vegetation affects: Trampling
Trampling is the mechanical exertion of force on a vegetative structure. The total amount of damage inflicted on vegetation can be understood as a function of the energy released onto the structures by the means of transportation (York, 2000). Terence York has developed a general model for understanding the varying impact of different modes of travel:

Land Impact = ((weight + output acceleration) x swath)).

In the above equation, "Output Acceleration" is defined as vehicle power (horsepower) divided by its mass. "Swath" is the width of the vehicles track (tire, foot, or tank-style track) multiplied by its length of travel.

York's methodology provides a very useful analytic framework for examining the amount of energy transmitted to plant structures by various modes of travel. He applies this formula to a range of common modes of transportation, from hiker to military battle tank.

There are some problems with this method of measuring a vehicle's impact on land, particularly when evaluating a specific user type in a specific area. For example, it has been shown that motorcycles actually widen and deepen downhill sections of trail less than horses, but more than horses on uphill sections of trail (Weaver, 1978). This is explained by the fact that walkers (human or animal) must check their speed as they proceed downhill by generating friction with the ground surface. Wheel-driven vehicles can check their speed by using braking mechanisms integral to the vehicle, without necessarily applying a shearing force to the soil surface. Though, again, operator skill and decisions can influence this, as in the case of a novice mountain biker skidding downhill.
These problems with applying this framework to actual results in the field cited above, suggest some limitations as a practical tool for managing land use. However, according to York, "the weight, power, and swath equation that was presented here is consistent with long term observations of vegetation, soil, and pavement changes following land use" (York, 1997).

York (1997) further conducted a meta-analysis of the 400 citations dealing with the impact of foot and vehicle impacts on vegetation, "Toleration of Traffic by Vegetation: Life Form Conclusions and Summary Extracts from Comprehensive Data Base" (York 1997). In this study, he distilled the data into a uniform Access database format. York's work provides a very useful examination of trampling studies, only two thirds of which were sufficiently detailed for York to normalize the data for the purposes of his database. With others he made some compromises, reducing the level of detail in some to allow comparability among various data sources.

Given the constraints he faced in aggregating diverse studies utilizing differing endpoints, York reached some interesting conclusions about the effects of trampling. First, graminoids appear to have the greatest resistance and recovery capacity among plant forms. Climbers and cactoids are the most vulnerable overall to trampling. Shrubs and trees suffer the greatest long-term reductions in diversity following traffic impact.

While all vegetation forms suffer impact linearly increasing from added traffic as predicted by York's (2000) overall formula, this database is telling in its lack of attention to the affects of mountain bikes specifically. None of York's records includes a specific mention of the application of trampling by mountain bike users, though an otherwise wide array of conveyances is listed (from hikers to armored vehicles).

I can only speculate as to the reason from personal observation: Unlike other user groups, there is very little use of mountain bikes off-trail. In fact, for the majority of the mountain bikers, the trail is the most desirable place to ride for safety and pleasure. Hikers often wander off trail, regarding their own diffuse impact as negligible. Other groups, such as ORVs and four-wheel drive light trucks often regard off-trail travel as the point of their sport. Military tank are used off-trail in a localized but intensive manner for training purposes.

York's work provides a macro-level analysis of the various mechanisms by which human movement through ecological systems damages vegetation. However, it does not provide an in-depth examination of effects on a very local level. York's work is in part a response to the difficulty in making management decisions based on all the extant knowledge about trampling on vegetation (York, 1997).
Cole and Bayfield (1992) proposed a set of standard experimental procedures for studying the recreational trampling of vegetation. This is an effort "to promote an increased ability to compare results from different studies" (Cole and Bayfield, 1993). When such forces are applied, changes in vegetation can be measured using two primary measures, relative cover and relative height. In both cases, "conditions after trampling are expressed as a proportion of the initial conditions, with a correction factor applied to account for spontaneous changes on the control plot (Cole and Bayfield, 1992).

Relative cover, using Cole and Bayfield (1992) methodology, can be expressed as:

Relative Cover = (surviving cover on trampled subplots / initial cover on trampled subplots) x correction factor x 100%

The advantage of measuring relative cover is that it serves as good measure of total plant mortality and recovery. It can be measured for either overall total vegetation or by individual species. This enables an observer to determine if certain plant species are affected disproportionately to others, as less resistant species occupy ground lost to trampling effects. Total cover may remain constant, but species proportion change.

Total height is calculated by Cole and Bayfield (1992) by adding the height measures of a fixed number of observations per sample plot and dividing by the total number of observations to obtain a mean height. These mean height numbers can be substituted in the formula for cover above to obtain relative height. Relative height provides a sensitive quantification of trampling effects where total cover is not reduced (e.g. where trampling is intermittent and modestly damaging).

Thurston and Reader (2001) attempted to specifically compare the trampling affects of mountain biking and hiking through the use of a controlled experimental design. This is the only citation I could find to use a controlled experiment to ascertain the differential trampling effects of mountain biking versus hiking on vegetation.

Thurston and Reader (2001) applied five different intensities of experimental use to test lanes in Boyne Valley Provincial Park, Ontario, Canada. The intensities of treatments were 0, 25, 75, 200, and 500 passes each for hiking and mountain bicycling. Before and after these treatments they measured plant stem density, species richness, and soil exposure. They made follow up measurements of these endpoints at two weeks and one year after treatment. They found no significant differences between the mountain biking and hiking plots. Both stem density and species richness were reduced by nearly 100% at the highest treatment intensities, but recovered within the study period to pre-treatment levels. From this they conclude that both mountain biking and hiking impose fairly similar short-term damage and that vegetation recovers quickly once either use is halted.

This study is useful in that it is the only study to use a controlled experimental design to measure the trampling effects of mountain biking and hiking on untrammeled vegetation. More studies like it in different ecological areas and with different treatment intensities would be useful. However, it suffers from some weaknesses that limit its real world applicability. Chiefly, this study's treatment passes at best loosely approximate the forces exerted by actual mountain biking. On real trails, riders possess widely varying levels of skill, resulting in variant speeds, turning, and braking. This study does not address these variables.

Soil and trail affects: Mechanical erosion

Most literature examining the direct effects of a recreational use on the surface of the soil itself focus on pre-existing trails. Most of these studies examine the factors that contribute to the degradation of trails by all user groups. Few studies have attempted to compare various user class effects on the trails. These studies differ significantly in that they examine the effect of recreational use on trails, which can be considered a form of environmental impact themselves.

In the August 1999 issue of Outside magazine, Jill Danz wrote, "a 1987 effort, funded by the U.S. Department of Agriculture, found that only one user group clearly messes up wild places, those who build trails in the first place. Every group's impact after that is relatively negligible." This study highlights one of the key challenges in studying the effect of mountain bikes and other user groups on ecological systems. The majority of damage off-trail is done by the very earliest activity-whether sanctioned (trail building) or not (off-trail travelers). As such, in the context of an existing trail, it may be the case that distinctions between user groups are less meaningful than most other factors, including enforcement of regulations, overall use level, ground conditions, and topography. Some studies discussed below tend to reinforce this.

Weaver and Dale (1978) examined the differential effects of these three user groups on trails in a northern Rocky Mountain ecosystem. The authors assert that theirs is the first study comparing differences between user groups. In the study, the investigators applied 1000 passes each from hikers, motorcycles, and horseback riders in a meadow and a forested area, both in Montana.

They found that the percentage of ground eroded bare increased with the number of applied passes and that the exposure was more rapid on sloping sites than on level sites. On level ground horseback riders cause the most damage and hikers the least. On grassy, sloped terrain, motorcycles cause more damage than horses. Hikers in all situations cause substantially less damage than all other user groups. Most importantly there is a non-linear relationship in most situations and user group combinations between damage done and number of treatment passes. Early users widen and deepen trails much more than later users. This suggests managers can limit unplanned compaction and vegetation damage by appropriately planning and building the trail in the first place.

This study's strength was the number of experimental passes applied and the number of endpoints examined, including sediment erosion measurements as well as vegetation trampling. However, its chief weakness today is the motorcycle used-a Honda Trail 90 built in the 1970s (one of which this review's author rode many thousands of miles while on family camping trips in elementary school). The Honda Trail 90 is a small, fat-tired motorcycle with an engine much lower in power than even the very smallest of today's off-road motorcycles. It cannot be compared to the dirt bikes of today.

Kuss (1983) compared the difference between the effect of conventional lug-soled boots and corrugated rubber compound sole boots on woodland trails. While this study finds no difference between the two types of boots, it is frequently cited as a prototype methodology for examining different user classes' impact on hiking trails (in this case wearer's of lugged and non-lugged soles).

One study specifically compares the impact on trails of four user classes, hikers, horses, motorcycles, and off-road bicycles. Wilson and Seney (1994) applied experimental passes to various sites on an existing trail system in the Gallatin National Forest of Montana. They found that users on foot (hikers and horses) make more sediment available than do users on wheels (mountain bikes and motorcycles).

Wilson and Seney (1994) applied 100 experimental passes by hiker, horse, mountain bicycle and motorcycle to 108 sample plots on existing trails in the Gallatin National Forest of Montana. They then used a rainfall simulator to measure the amount of sediment mobilized during the rain event as a result of user-created soil disturbance. Using statistical analysis they found that about one third of total sediment mobilization could be attributed to the various user groups, and the remaining two thirds attributed to the solid texture and the slope of the sample trail plot. Further, they determined that feet (hooves and boots) made somewhat more sediment available than did wheels (motorcycles and bicycles).

The results of this study are much more applicable to the real world than, for example, Thurston and Reader (2002). First, they used many more test plots on trails that varied in slope, soil, and pre-existing moisture. Second, treatment passes were applied along longer lengths of trail, making it more likely that experimental behavior more closely approximated actual user behavior. Finally, they examined many more variables.

Wheels and feet

The available comparisons of wheeled and foot- or hoof-based methods of transportation measure endpoints associated with trail use, such as sediment mobilization or vegetative cover reduction. They do not directly attempt to describe the varying mechanisms by which these different modes transportation create these effects. For example, York's theoretical model comparing the total impact of different conveyances only accounts for the power, size, and distance traveled by a vehicle. While his model approximates the effect of these vehicles accurately (when validated against empirical data), it does disregard the mechanism (wheel or foot) through which these different modes operate on vegetation and soil. Weaver and Dale (1978) confirmed there may be meaningful differences in impact when comparing wheels and hooves/feet unrelated to power, weight, and distance traveled.

Quinn et al. (1980) found that the feet of a hiker damage trails and vegetation in two distinct phases. First the heel applies compaction in the first part of the step. Second, the toe applies shearing forces as it rotates through the step. Quinn et al. (1980) determined that this shearing accounted for the greatest share of a human foot's damage.

Wheels also apply both compaction and shearing damage, but they do so in different ways (Cessford, 1995). Wheels apply a constant swath of compaction, unlike feet, which apply an interrupted series of localized compactions. However, wheels apply shearing force to the ground either during acceleration or braking (Cessford, 1995). In this, mountain bikes and motorcycles will differ greatly as a motor has the ability to exert sustain shearing force over time and uphill. Such loss of traction for a mountain bike causes a halt to forward progress and cannot be sustained meaningfully.

Keller (1990) described some other ways that wheels will impact ground surfaces differently. For example, because wheeled vehicles create long, continuous swaths of wear, they may be more prone to "channelizing" the soil (the creation of gullies through which water can readily flow). Wear caused by feet create discontinuous pockets of disturbance less likely to result in such gullies. This effect remains untested, however, in a controlled experimental design.

Cessford (1995) noted that the mechanism of compaction, when applied to a hardened, planned trail should not be considered damage per se, as a compacted soil surface is an intentional design aspect of backcountry trails. Shearing, particularly when associated with water flows, does cause damage to existing trails, but this is generally an issue for the trail engineer whose design should result in a trail capable of handling the demands of the planned user groups.

Wildlife affects: Disturbance

The studies discussed so far look at the mechanical impact of mountain bike recreation on vegetation and soil. Another key area of concern is the effect of mountain bike recreation on wildlife. There are two basic mechanisms by which mountain bikes can affect wildlife populations:

- Direct mortality: Impact at high speed resulting in death-in practice, this only affects small animals.
- Disturbance: Changes in animal behavior associated with the presence of recreational users in their habitat.

Direct mortality is virtually unstudied. I could find no references to it in the literature. Anecdotal evidence suggests, however, that small mammals are vulnerable to impact and are not uncommonly killed (Switalski, pers. comm.).

While a great deal of literature exists on the effect of human recreation on animals, very little of it attempts to compare the effects of mountain bikers with those of other user classes. Difficulties in study design may be a main obstacle to such comparative studies. In studying influences on vegetation and soil, controlled, experimental designs can be readily conducted. While first-hand observation of animals can possibly show differences in response to various recreational user classes, in most areas it is not realistic to separate the effects various user groups have on wildlife populations over time.

Animals will exhibit one of three responses to the presence of humans in their environment: attraction, avoidance, and habituation (Knight, 1995). For mountain bike recreation, the most important of these are avoidance and habituation. Attraction is most commonly associated with food availability, where animals are conditioned to approach humans in search of food.

While study design is very problematic when looking at the effect of one specific user class on wildlife, opportunities do present themselves. Stake (2000) looked at the impacts of mountain biking activity on golden-cheeked warblers at Fort Hood, Texas, a military training area. In 1998, a local mountain biking club was allowed by the U.S. Army and U.S. Fish and Wildlife Service to open a mountain biking park at the Belton Lake Outdoor Recreation Area on Fort Hood in Texas. The golden-cheeked warblers in the area had already been under study by Stake, so he was able to make direct comparisons between the area before and after. He reported no impacts from the new mountain biking activity on Warbler territory density, return rates, or age structure (Stake, 2000).

Such opportunities to look at the effect of mountain biking before and after introduction to a given area are rare, however. A more typical study is that conducted by W.

Sue Fairbanks, who looked at the distribution of pronghorn antelope on Antelope Island. This island in the Great Salt Lake of Utah was once home to a native population of pronghorn antelope. After being hunted to extinction, wildlife recovery teams reintroduced the species to the island in the 1980s. In 1983, a flood destroyed the causeway providing vehicle access to the island. In the 1990s, the island was re-opened to recreational use. The addition of recreational access created an opportunity to study the effect of people on the pronghorn population (Fairbanks, 2002).

Fairbanks (2002) measured the distance from recreational trails that pronghorn antelope tended toward before and after the re-introduction of human recreation. She found that pronghorn antelope did in fact alter their behavior based on the presence of humans, moving and staying further from the trails and recreational corridors after the re-introduction of human use than before. The smallest groups of pronghorn tended to stay further from recreational trail areas than did the larger groups, particularly groups with mixed sex and fawns. From this, Fairbanks (2002) concluded that pronghorn are affected by non-consumptive recreation (activities that do not involved killing of wildlife) and that management strategies should incorporate this in planning use rules.
The chief drawback of this study for the purposes of this paper is that it does not (and could not have) separated out the affects of various user groups. As a result it provides only a perspective for management of all recreational use. In addition, this study examines only short-term behavioral changes, which may or may not have implications for long-term population viability.

Antelope Island was also used by a graduate student at Colorado State University, Audrey Taylor, to examine the differential effect of hikers and mountain bikers and several species, including bison, mule deer and pronghorn antelope. Taylor (2001) observed and calculated the probability of each animal flushing when approached by both hikers and bicyclists. Taylor (2001) found no difference between mountain bikers or hikers in flushing response. For both user groups, alert distance and flushing distance did not significantly vary (Taylor, 2001).

Taylor (2001) concluded that short-term behavioral changes do not vary between bicyclists and hikers on a per encounter basis. However, because bicyclists are capable of and, in most areas, typically do travel much farther than hikers; it is reasonable to conclude that they will create a somewhat higher total number of encounters and flushings. In addition, Taylor's (2001) methodology does not attempt to measure long-term population changes in the animals studied.

Future research needs
Taylor (2001) asserted "Mountain biking is emerging as a form of outdoor recreation which may compete with more traditional forms of recreation, such as hiking, for space on public lands. Virtually nothing is known about whether wildlife respond differently to mountain biking versus hiking" (emphasis added). Little is also known about the erosion and trampling effects of mountain biking. More research is needed in both areas to help inform the development of local management regimes.
Three broad areas should be given priority for study: (1) mountain biking styles, (2) broad behavioral differences, and (3) long-term population studies.

Broad behavioral differences
This area of inquiry should be pursued using sociological survey techniques. It would seek to understand some of the specific chosen behaviors exhibited by mountain bikers versus hikers. Accompanying it should be a series questions about the value systems of the two user groups. The main purpose would be to find answers to such questions as:

- Are mountain bikers more likely to cut switchbacks?
- Do mountain bikers litter more or less often than hikers?
- How often do mountain bikers go off trail?

Because these behaviors are not inherent to the bicycle as a mode of transportation, the management of adverse ecological effects caused by them would fall to local management and enforcement.

Mountain biking styles
Some aspects of mountain biker behavior, however, should be comparatively studied using many of the same controlled scientific study designs used in the various works discussed in this literature review. For example, some mountain bikers will travel faster than others, skid more going downhill, or jump logs more often. In order to understand how much trampling, erosion, and wildlife disturbance mountain bikes cause, factors like these should be introduced as variables in studies examining these endpoints. One could suggest that experimental treatment passes or experimental harassment of wildlife would not be a reliable source of data if such factors as speed and propensity to skid were not introduced as variables.

Long-term population studies
The most important-and certainly most difficult-research need made evident by the extant literature on mountain biking and wildlife is the need for more long-term population studies comparing the effects of various user classes. In practice, few opportunities such as Stake (2000) are available. It is, in most cases, impossible to sort out the long-term effects of various user groups on an animal population. However, for macro-level management of natural areas, such studies are the most important for securing wildlife health.

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