Mountain Biking: A Review of the Ecological Effects

February 2010

Prepared by Michael Quinn and Greg Chernoff

MIISTAKIS INSTITUTE

Prepared for: Parks Canada – National Office (Visitor Experience Branch)

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FINAL REPORT

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EXECUTIVE SUMMARY

In order to inform an activity assessment of mountain biking within Canada's national protected heritage places, Parks Canada commissioned the following literature review on the ecological effects of mountain biking. The purpose of this review was to summarize the nature of the ecological perturbations or effects arising from the disturbance of recreational mountain biking. Extensive searches and cross-references were conducted using the most relevant on-line databases available through the University of Calgary library. Searches of the World Wide Web via leading search engines and focused reviews of known mountain biking and trail associations were also conducted. The intent of the initial search was to identify as many papers, reports and theses as possible that addressed topics related to mountain biking. Source materials were then filtered to identify those references that addressed ecological effects of the activity. The research described in this report is concurrent with a complementary effort to understand the demographics, culture, and social effects of mountain biking as a recreational activity.

Mountain biking is a popular and burgeoning recreational activity. Compared to other outdoor recreational activities, there is a relative dearth of understanding and peer-reviewed scientific papers on the ecological effects of mountain biking. The original objective of this literature review was to provide a comparison of published research on the relative effects of four distinct sub-disciplines of mountain biking: cross country, freeride, downhill and bike parks/dirt jumps. However, the lack of published literature focusing on the sub-disciplines, or the comparison between them, made this impossible. Therefore, the review provided herein primarily addresses cross-country riding. Specific effects associated with mountain biking activity and infrastructure characteristic of the other types of use have emerged as a considerable gap in the research literature.

The literature review was conducted within the framework of recreation ecology – the study of the biophysical effects of recreational activity. One of the most important theoretical generalizations arising from recreation ecology is referred to as the curvilinear use-impact relationship. In simple terms, the nonlinear nature of the use-effect relationship suggests that the greatest proportion of ecological effect is generated during the initiation and early use period of a new facility or infrastructural development. This phenomenon has been clearly established for a wide variety of soils and vegetation responses to activity, and suggests that the majority of the environmental effect occurs when a trail is first developed or constructed.

The review followed the approach used in the majority of the recreation ecology literature, exploring the ecological effects of the activity on soils, vegetation, water and wildlife individually. Although this framework provides a useful structure in which to discuss the effects of recreation, it is essential to recognized that there are connections, feedbacks and synergies between the categories. Ultimately, effects of disturbance must be addressed with an understanding of the cumulative and synergistic nature of their occurrence.

The available published literature indicates that mountain biking as an anthropogenic disturbance is similar in its environmental effects as other forms of summer season trail use. The effects of mountain biking on soils and vegetation have received the most attention and experimental

examination of the four categories. Research has mainly focused on quantifying erosion (created by shear forces) and compaction (created by normal forces) that result from mountain bike use and combine to create "tread incision". Other concerns include water runoff and resulting sediment transport (erosion), and trail widening to avoid muddy or puddled areas. As with other forms of trail-based recreation (hiking, horseback riding), research has shown that the soil type (erodability), terrain relief and amount of moisture have the greatest influence on the significance of mountain biking effects on soils. Researchers also reported that cycling technique and skill level influences the level of impact on soils, with braking/skidding and cutting switchbacks creating the most damage**.** Vegetation trampling and removal generally follows the curvilinear use-effect relationship described above with de-vegetated trails appearing even after relatively low levels of use. Mountain bike trails as vectors for the spread of non-native exotic plant species has been identified as a concern, but little empirical work is available to draw any conclusions beyond the knowledge that exists for other similar hiking and horse trails. The current review was unable to find any published research on the effects mountain biking on water quality.

The effects of mountain biking on wildlife are primarily related to habitat alteration as a result of impact to soils and vegetation, as well as disturbance of daily or seasonal habitat use. The significance of the disturbance is related to the type, timing, intensity, duration and spatial distribution of use. One of the most significant characteristics of mountain biking as a form of wildlife disturbance is a result of the potential relative speed and silence of the activity. A relatively fast moving, quiet mountain biker may approach an animal without being detected until well within the normal 'flight response zone'. The result may be a severe startle response by the wildlife species with significant consequences to the animal and/or the mountain biker. In the case of grizzly bears, such incidents may result in aggressive behaviour toward the mountain biker. In the case of bison, elk and pronghorn antelope, one study did not reveal a significant difference between hikers and mountain bikers with respect to the reaction of any of the three species to their presence.

This review clearly identifies significant gaps in the available literature to assess the ecological effects of mountain biking. Some of the most important knowledge gaps include: 1) To date, there have been few documented interdisciplinary studies of the environmental and social effects associated with mountain biking; 2) Very little has been studied of the recreational ecology of mountain bikes in the Canadian context. Since many of the environmental effects are known to vary according to regional geophysical traits, applying research carried out in other biomes and landscapes may be problematic. Similarly, there are few studies outside of mountainous and high relief terrain areas; 3) No specific research has been published on the water-related environmental effects of mountain biking; 4) Some more focused study of the effects of mountain biking on wildlife would be of benefit; 5) Existing research focuses mainly on the type of recreational activity with little or no emphasis on the timing, intensity, duration and spatial distribution of the activity. Furthermore, there is little in the literature to differentiate between different types of mountain biking; 6) There is a tremendous need for research that addresses the cumulative effects of human recreational activity in protected areas. This includes the need to identify thresholds associated with numbers, timing, type and distribution of use.

SOMMAIRE

Parcs Canada a fait établir la présente analyse documentaire dans le but de contribuer à l'évaluation nationale du vélo de montagne pour les aires patrimoniales protégées du Canada et de résumer la nature des effets ou des perturbations écologiques découlant de cette activité. Pour ce faire, on a rassemblé le plus de documents possible sur le vélo de montagne (articles, rapports, thèses, etc.) en réalisant des recoupements et des travaux de recherche poussés au moyen des bases de données pertinentes de la bibliothèque de l'Université de Calgary, en menant des recherches Internet grâce aux moteurs de recherches les plus couramment utilisés et en effectuant un examen ciblé de diverses associations bien connues dans le domaine du vélo de montagne et des sentiers. De ces documents, on n'a ensuite retenu que ceux portant sur les effets écologiques de l'activité. La recherche dont il est question dans le présent rapport s'inscrit dans un effort complémentaire de compréhension des effets démographiques, sociaux et culturels du vélo de montagne en tant qu'activité récréative.

Le vélo de montagne est une activité récréative populaire et florissante. Cependant, ses effets écologiques sont plutôt méconnus, et il n'existe que très peu d'articles scientifiques évalués par les pairs sur le sujet, comparativement aux autres activités de plein air. Le premier objectif de la présente analyse documentaire était de fournir un examen comparatif des effets relatifs de quatre sous-disciplines distinctes du vélo de montagne, soit le cross-country, le freeride, la descente et les parcs de vélo/sauts en terre battue. Toutefois, le manque de documentation publiée sur ces sous-disciplines ou le manque de comparaisons entre elles rend cette tâche impossible. Par conséquent, la présente analyse concerne principalement le cross-country. En ce qui concerne les effets spécifiques associés au vélo de montagne et aux caractéristiques de l'infrastructure des autres types d'utilisation, on a constaté qu'il y avait une lacune considérable sur le plan des comptes rendus de recherche.

On a mené la présente analyse documentaire dans le cadre de l'écologie de récréation – l'étude des effets biophysiques des activités récréatives. L'une des généralisations théoriques les plus importantes que l'on peut tirer de l'écologie de récréation a trait à la relation non linéaire entre l'utilisation et les effets qui en découlent. En termes simples, l'existence d'une relation utilisation-effets de nature non linéaire tend à montrer que la majeure partie des effets écologiques se manifestent lors de la période d'initiation et des premières utilisations d'une nouvelle installation ou infrastructure. Ce phénomène a été clairement établi dans le cas d'une grande variété de sols et de végétation, et laisse entendre que la majorité des effets sur l'environnement se produisent lors de l'aménagement d'un sentier ou de la construction d'une installation.

La présente analyse a été réalisée suivant l'approche utilisée dans la majorité des documents sur l'écologie récréative, qui consiste à explorer individuellement les effets écologiques de l'activité sur quatre grandes catégories, soit les sols, la végétation, l'eau et la faune. Bien que ce cadre fournisse une structure utile favorisant l'examen des effets de l'activité récréative, il est essentiel de reconnaître qu'entre ces différentes catégories, il existe des liens, des réactions et des synergies. En définitive, il faut connaître la nature cumulative et synergétique des effets de la perturbation pour arriver à les contrer.

Selon les documents consultés, les effets qu'entraîne sur l'environnement le vélo de montagne en tant que perturbation anthropique sont similaires à ceux découlant des autres formes activités de sentier pratiquées pendant la saison estivale. Les effets du vélo de montagne sur les sols et la végétation sont, des quatre catégories, ceux qui ont reçu le plus d'attention et fait l'objet du plus d'examens expérimentaux. Les recherches étaient principalement axées sur l'érosion quantifiable (créée par les forces de cisaillement) et sur la compaction (créée par les forces normales) qui résultent de l'utilisation du vélo de montagne et se combinent pour créer une « bande de roulement ». Parmi les autres préoccupations figurent aussi l'écoulement de l'eau et l'amenée de sédiment qui en résulte (l'érosion) ainsi que l'évitement des passages boueux et glaisés entraînant l'élargissement des sentiers. Comme pour les autres formes d'activités de sentier (par exemple, la randonnée et l'équitation), la recherche montre que le type de sol (caractère érodable), le relief du terrain et le taux d'humidité ont une grande incidence sur l'importance des effets du vélo de montagne sur les sols. Des chercheurs indiquent que les techniques de vélo et le degré d'habileté peuvent aussi avoir une incidence; en effet, le freinage, le dérapage et les virages dans les sentiers en lacet peuvent entraîner des dommages importants. Les dommages causés par le piétinement ainsi que l'élimination de la végétation suivent la relation utilisation-effets non linéaire décrite plus haut; des chemins dépourvus de végétation se forment malgré une utilisation relativement modérée des sentiers. Le fait que les sentiers de vélo de montagne constituent un vecteur de propagation d'espèces végétales exotiques soulève également des préoccupations, mais il n'existe pas suffisamment de travaux d'observation sur le sujet pour permettre de tirer des conclusions autres que celles qui existent déjà pour les sentiers de randonnée et d'équitation. Dans le cadre de la présente analyse, il a été impossible de trouver des documents publiés concernant les effets du vélo de montagne sur la qualité de l'eau.

Les effets du vélo de montagne sur la faune sont principalement liés à la modification de l'habitat, qui découle de l'incidence sur les sols et la végétation, et à la perturbation causée par l'utilisation quotidienne ou saisonnière de l'habitat. L'importance de la perturbation est liée au type et au temps d'utilisation, ainsi qu'à son intensité, à sa durée et à sa distribution spatiale. L'une des principales caractéristiques de la perturbation de la faune qu'entraîne le vélo de montagne résulte de la vitesse relative des vététistes et du caractère potentiellement silencieux de l'activité. Un vététiste silencieux roulant relativement rapidement peut s'approcher d'un animal sans se faire repérer et s'aventurer à l'intérieur de la « zone normale de fuite ». Dans une telle situation, les animaux sauvages peuvent avoir une vive réaction de sursaut entraînant des conséquences graves pour l'animal ou pour le vététiste. Le grizzly, par exemple, peut adopter un comportement agressif envers le vététiste. Selon une étude, la réaction que produit un vététiste sur le bison, le wapiti et l'antilocarpe ne serait pas tellement différente de celle que produit un randonneur.

La présente analyse montre clairement qu'il existe des lacunes importantes dans les documents publiés et que, pour cette raison, il est très difficile d'évaluer les effets écologiques du vélo de montagne. Parmi les lacunes les plus importantes, on trouve celles qui suit : 1) Jusqu'à aujourd'hui, on a mené peu d'études interdisciplinaires documentées sur les effets sociaux et environnementaux découlant du vélo de montagne. 2) On en connaît très peu sur l'écologie récréative liée au vélo de montagne au Canada; comme un grand nombre d'effets environnementaux varient en fonction des caractéristiques géophysiques régionales, l'application des résultats de recherche obtenus dans d'autres biomes et types de paysages peut d'avérer problématique. De plus, très peu d'études ont été menées à l'extérieur des aires montagneuses et de haut-relief. 3) Aucun travail de recherche n'a été publié concernant les effets environnementaux du vélo de montagne sur l'eau. 4) Il serait utile de mener davantage de recherches axées sur les effets du vélo de montagne sur la faune. 5) Les recherches actuelles mettent principalement l'accent sur le type d'activité récréative, mais se concentrent peu, voire pas du tout, sur le temps, l'intensité, la durée et la distribution spatiale de l'activité. De plus, on trouve peu d'information permettant de faire la différence entre les différentes disciplines de vélo de montagne. 6) Il faudrait absolument effectuer des recherches sur les effets cumulatifs de l'activité récréative humaine dans les aires protégées. Il est notamment essentiel de déterminer les limites associées à la fréquence, au temps et au type d'utilisation, ainsi qu'à sa distribution.

INTRODUCTION

In order to inform an activity assessment of mountain biking within Canada's national protected heritage places, Parks Canada commissioned the following literature review. This report reviews both peer-reviewed scientific and grey literature sources, and represents not a comprehensive or exhaustive study of available literature, but rather a solid foundational overview upon which future efforts can hopefully build.

Throughout this review the authors assume that mountain biking constitutes an anthropogenic 'disturbance' to the physical environment in which it occurs. An ecological disturbance is "A cause; a physical force, agent, or process, either abiotic or biotic, causing a perturbation (which includes stress) in an ecological component or system; relative to a specified reference state and system; defined by specific characteristics" (Rykiel 1985, p. 364). Disturbances create changes to the background or 'average' environmental conditions that may be short-term, long-term or permanent. "Outdoor recreation, including nature-based tourism, has long been recognized as an agent of ecological change in natural systems, with the potential to affect soil, vegetation, wildlife, and water quality" (Monz et al. 2010). Whether such change is positive, negative or neutral is entirely a human construct based on societal values. The purpose of this review is to summarize the nature of the ecological perturbations or effects arising from the disturbance of recreational mountain biking. Although the term 'impact' is, by definition, value neutral (e.g., "the effective action of one thing or person upon another; the effect of such action; influence; impression", Oxford English Dictionary [online version] 2010) the term 'environmental impact' is generally received by the natural resource management community as referring to negative conditions or outcomes. Therefore, for the purpose of this review, we will primarily refer to the environmental 'effects' of the 'disturbance' (i.e., mountain biking).

The authors are confident that the references and annotated bibliography included in this document include the vast majority of papers, theses and reports dedicated solely to the assessment of the ecological effects of mountain biking. Extensive searches and cross-references were conducted using the most relevant on-line databases available through the University of Calgary library (e.g. Environmental Abstracts, ENVIROnetbase, Environment Complete, Wildlife & Ecology Studies Worldwide, Scopus, Web of Science, Index to Theses, Theses Canada Portal, ProQuest Dissertations and Theses). The majority of searches were conducted using the search terms 'mountain bike or biking'. This ensured that all literature pertaining to mountain biking was identified. Resultant titles and abstracts were then searched to identify those papers/reports/theses that addressed issues of ecological effects We included the search term 'impacts' as the term is commonly included in the literature. We also searched the World Wide Web using Google, Google Scholar and specific searches of known mountain biking and trail associations. Existing review papers were used as a means to validate our search results. We subsequently reviewed, summarized and synthesized all available, relevant material within the time constraints of the contract. An annotated bibliography of selected sources is included as Appendix A.

There are several existing literature reviews that address the ecological effects of mountain biking on wildlands. Cessford (1995) reviewed studies on environmental and social effects of mountain biking, focusing on examples from the US and Australia. Lathrop (2003) published a literature review for an American conservation advocacy group, counterbalanced by Marion & Wimpey's (2007) science review that was supported by the largest mountain bike advocacy group in the world, the International Mountain Bike Association (IMBA). A more recent treatment was published by Pickering et al. (2010), who conducted a comprehensive review of studies related to the environmental effectss of hiking, horseback riding and mountain biking, focusing mainly on examples from the US and Australia. As with any topic, there are reports that present a particular normative position (e.g., Vandeman (2004) versus Sprung (2007)). In other words, some of the grey literature is clearly written to advocate for or against mountain biking in protected places. Therefore, we have relied primarily on literature that has been peer-reviewed wherever possible. In reviewing material that may have been biased, we attempted to focus on the primary evidence and not the opintions or conclusions of the authors.

The research described in this report is concurrent with a complementary effort to understand the demographics, culture, and social effects of mountain biking as a recreational activity. As such, we have reviewed little of the research that has been done on this subject with the understanding that it will be given fair treatment elsewhere. There exists, however, a grey area between human and ecological elements of this topic. Moreover, it is essential that these dimensions be integrated in an interdisciplinary approach that fully addresses the complexity of the management issues of importance to the managers of national protected heritage places and those participants in the activity assessment for mountain biking. The management of human recreational activity in national protected heritage places is ultimately about articulating and managing for an acceptable level of change. A sampling of studies on the social effects of mountain biking are included in later sections, where we discuss some research and management questions that arise from our findings.

Mountain Biking

Mountain biking is a popular and burgeoning recreational activity. From its humble beginnings in Marin County California in the early 1970's, it has grown to become an immensely popular recreational activity with at least one mountain bike in 52% of all Canadian households (Mosedale 2003, p.19). Compared to other outdoor recreational activities, there is a relative dearth of understanding and peer-reviewed scientific papers on the ecological effects of mountain biking (Newsome and Davies 2009). For example, the most recent peer-reviewed literature review that includes the environmental effects of mountain biking included only 11 published papers in the review (Pickering et al. 2010).

Within mountain biking there are a number of distinct disciplines (modified from the Statement of Work for this review):

1. **Cross-Country (XC)** is the most common form of mountain biking, practiced on trails that feature a wide variety of terrain and routes that consist of uphill, downhill and flat sections – often on trails that were originally developed for some other intended use (e.g., hiking). Trail types can vary from flat dirt roads to technical rocky/rooty singletrack, may include technical trail features, and can vary in length. Typical XC riders are self-sufficient and looking for solitude, nature, exercise, and challenge from their recreational experience. The type of bicycle used for this discipline will range from bikes that are more traditional looking with little or no suspension to more durable bikes with longer-travel suspension and aggressive tires. Slightly more technical and aggressive XC riding is sometimes referred to as trail or all-mountain riding.

2. **Freeride** is a discipline between cross-country mountain biking and downhill mountain biking. Aside from the usual climbing and descending found in cross-country, freeriding involves specific bike-handling skills and techniques and can practiced with natural and constructed obstacles that are either off-trail or can be included as part of a cross-country trail. The vehicle used for this discipline often has dual suspension and is lighter than downhill but heavier than XC bicycle.

3. **Downhill** - This gravity-assisted discipline involves manoeuvring a sustained descending trail that ends at a lower altitude than the start, requiring the rider to either push, shuttle (with a motorized vehicle or ski lift), or less commonly pedal his/her way to the top. The terrain for downhill trails can be steep and often includes jumps, drops, rocky sections, and roots. Participants are seeking challenge and speed, in some cases reaching speeds of 85 kilometres per hour. The downhill mountain biker requires a high level of technical skill, control, quick reflexes and intense concentration. The equipment used for this discipline is a downhill mountain bike specifically designed for descending challenging trails, which is heavier and more impact-resistant than freeride mountain bikes. It also has aggressive tires and participants commonly wear protective gear (e.g. downhill (full-face) helmet, goggles, body pads, etc.).

4. **Bike Parks and Dirt Jumps** - Bike parks usually consist of a variety of natural obstacles such as rocks and logs, constructed features such as ladder bridges, pumptracks and mounds of dirt for jumping over, all arranged in a controlled and confined area. This discipline requires a specific set of technical skills and bike-handling techniques. The types of bicycle used can include jumping-specific models of mountain bikes (called "dirt", "park", or "DJ" bikes), as well as all other types of mountain bikes. Dirt jumps are courses that include a series of mounds of dirt placed strategically to ride over, around or jump from. Constructed terrain may include dirt jumps, berms, etc. Similar to freeride, mountain biking, bike park obstacles are constructed using soil, raw timber, and man-made materials.

In general "[i]mpacts are likely to be greater when riding is faster, less controlled, occurs on steeper slopes and in wetter conditions" (Pickering et al. 2010). In terms of required degree of alteration to the natural landscape and amount of infrastructure development (construction of bike-specific features), there is a clear continuum evident in the four mountain biking disciplines described above. Newsome and Davies (2009) provide a slightly expanded list of mountain bike riding styles and their potential effects (Table 1).

The original objective of this literature review was to provide a comparison of published research on the relative effects of each of these four disciplines, but with the exception of an editorial article that makes specific reference to off-trail free-riding (Ferguson 2008) and an Australian study that enumerated and mapped unauthorized bike-specific obstacle construction (Davies & Newsome 2009), the current body of knowledge (published literature) appears unable to accommodate such differentiation. Therefore, the review provided herein primarily addresses cross-country riding. Specific effects associated with mountain biking activity and infrastructure characteristic of the other types of use have emerged as a considerable gap in the research literature.

Mountain biking differs from other non-motorized recreational activities (e.g., hiking, horseback riding) via the mediation of travel by wheels. In a malleable substrate, these wheels have the potential to create a groove / single-track that may subsequently conduct water and facilitate erosion. Skidding and braking may also result in the bicycle wheels physically moving soil and vegetation. The activity may also occur at a greater speed than hiking or equestrian travel. The implications of this are twofold: 1) mountain bikes have the potential to rapidly approach animals without being detected, and 2) speed and mechanical advantage may allow mountain bikes to access relatively more terrain in a shorter period of time. In addition, access to existing trails may result in new trail proliferation as well as the alteration of terrain or construction of infrastructure for more technical mountain bike experiences. In most other respects, the following review indicates that mountain biking (at least trail-based) as an anthropogenic disturbance is similar in its environmental effects as other forms of summer season trail use.

Table 1. Analysis of rider styles.

Style	Requirements	Impact potential
Cross-country riding	The demands of this group embrace an interest in a wide range of trails and most mountain bike riding can fit into this category. Inexperienced riders tend to want to ride on wide, smooth dirt roads or dedicated bike paths for outdoor pleasure and exercise	Low speeds and no desire for technical difficulty Low risk on formed surfaces
Touring	Typically engage in longer trips including overnight stays. They are often carrying camping equipment in panniers and are looking for wide, gently sloping trails through natural areas	Low speeds and no desire for technical difficulty Low risk on formed surfaces
Downhill riding	Includes more experienced riders using highly sophisticated, full suspension bikes for descending technically challenging trails. Downhill bikes are usually heavy and this user group likes to have shuttle services or short cut tracks for pushing their bikes up to the trail	Heavy bikes and some degree of technical difficulty Moderate risk of natural surface trail degradation
Free riding	These riders are seeking technical trail features such as rocks, logs and elevated bridges, dirt jumps, drop offs and see-saws along with big jumps and tough descents to challenge rider skill (Webber, 2007). Such riders desire high-risk trails on unconventional (rough and unpredictable) terrain	High risk of off-trail riding High impact potential
Dirt jumping	These riders are looking for dedicated jumping areas and a mix of jumping styles. Jumps can be provided in a 'skills park' area or as part of a dedicated cross-country trail. Dirt jumpers also use a variety of bikes, including some specialised models	High environmental impact if not carried out in suitably planned and designed trail networks

(Newsome and Davies 2009, p. 239).

BACKGROUND – RECREATION ECOLOGY

Outdoor recreation soared in popularity following World War II when much of society saw an increase in disposable income, leisure time, improved access to information, advancements in technology, and the provision of recreational infrastructure (Gnieser 2000). Concomitantly, resource managers became acutely aware of, and concerned by, the environmental and social costs associated with recreational activity. The study of the biophysical effects of recreational activity is addressed by the field of recreation ecology (Liddle 1997). Recreation ecology is an applied science founded on the realization that recreation "impact is inevitable.... Avoiding impact is not an option unless all recreation is curtailed. Managers must make conscious decisions about tolerable levels of impact, and implement strategies that keep impacts within acceptable levels" (Cole 2004, 113). Although the studies of recreational effects have been conducted since as early as the 1920s (e.g., Meinecke 1928), it was not until the 1970s that long-term research programs were initiated to explore the effects of outdoor recreation on the receiving environment (e.g., Bayfield 1973, Liddle 1975, Cole 1978). The first textbooks dedicated primarily to issues of recreation ecology were published in the 1980s (e.g., Hammit and Cole 1987). Parks Canada has a long history in researching the effects of recreation on the biophysical environment. For example, extensive recreation effect studies and inventories were initiated in the Rocky Mountain National Parks in the 1970s (e.g., Geist 1971, 1975; Kuchar 1972, Landals and Knapik 1972; Landals and Scotter 1973; Leeson 1979; Lesko and Robson 1975; Nagy and Scotter 1974; Roemer 1975; Scotter 1976; Trottier and Scotter 1973) some of which were revisited in the 1990s (e.g., Achuff 1992, Scotter 1992). However, although Parks Canada has a reasonably long history in recreation ecology research, the work is limited in geographic scope and type of activity examined. In general, recreation ecology has tended to focus on single issues at relatively small scales. In order "for the field to advance, more attention needs to be given to other ecosystem attributes and to the larger aspects of environmental conservation occurring at landscape scales" (Monz et al. 2010).

We consider any disturbance to the ecological (biophysical) system resulting from recreational engagement by humans to be an ecological effect or perturbation. We focus herein on ecological effects that result in undesirable changes to the environment. The *significance* of such undesirable changes to the receiving environment is a function of the activity (type, timing, intensity, duration and spatial distribution) and the sensitivity of the environment (resistance and resilience) including the morphological characteristics of vegetation, the nature of the substrate and the behavioural ecology of the species of interest (Fig. 1). In this review, we do not attempt to make any judgements about the acceptability of undesirable change as this is ultimately a management decision.

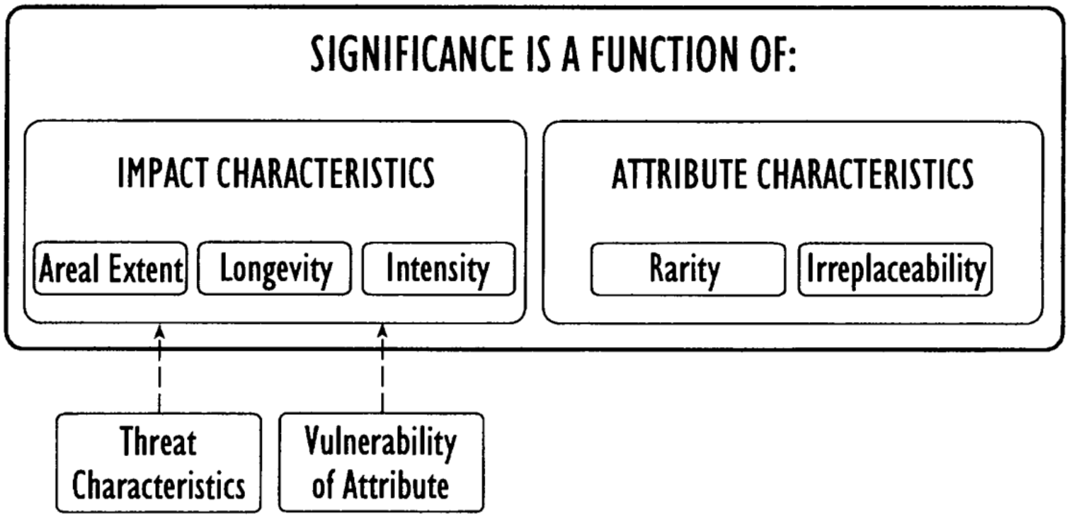


Figure 1. Criteria that help to define the significance of an ecological effect (Cole and Landres 1996).

This review is concerned principally with the environmental effects attributable to recreational activity, specifically mountain biking. A commonly used (Cessford 1995, Liddle 1997, Marion & Wimpey 2007, Mosedale 2003) and meaningful framework around which to organize these effects was first proposed by Wall and Wright (1977), and is illustrated in modified form in Figure 2. This approach divides major recreation effects into four main categories:

1. **Soil** – effects of activity on soil structure and composition, including increased erosion, compaction, and water runoff.

2. **Vegetation** – effects of activity on plant community composition, diversity, and structure.

3. **Wildlife** – the extent to which a recreational activity disturbs wildlife populations through mortality, removal/alteration of habitat, or behavioural stress or disturbance.

4. **Water** – effects of recreational activity on water resources, through introduction of nutrients or other pollutants, or as a transmitter of pathogens into a watershed.

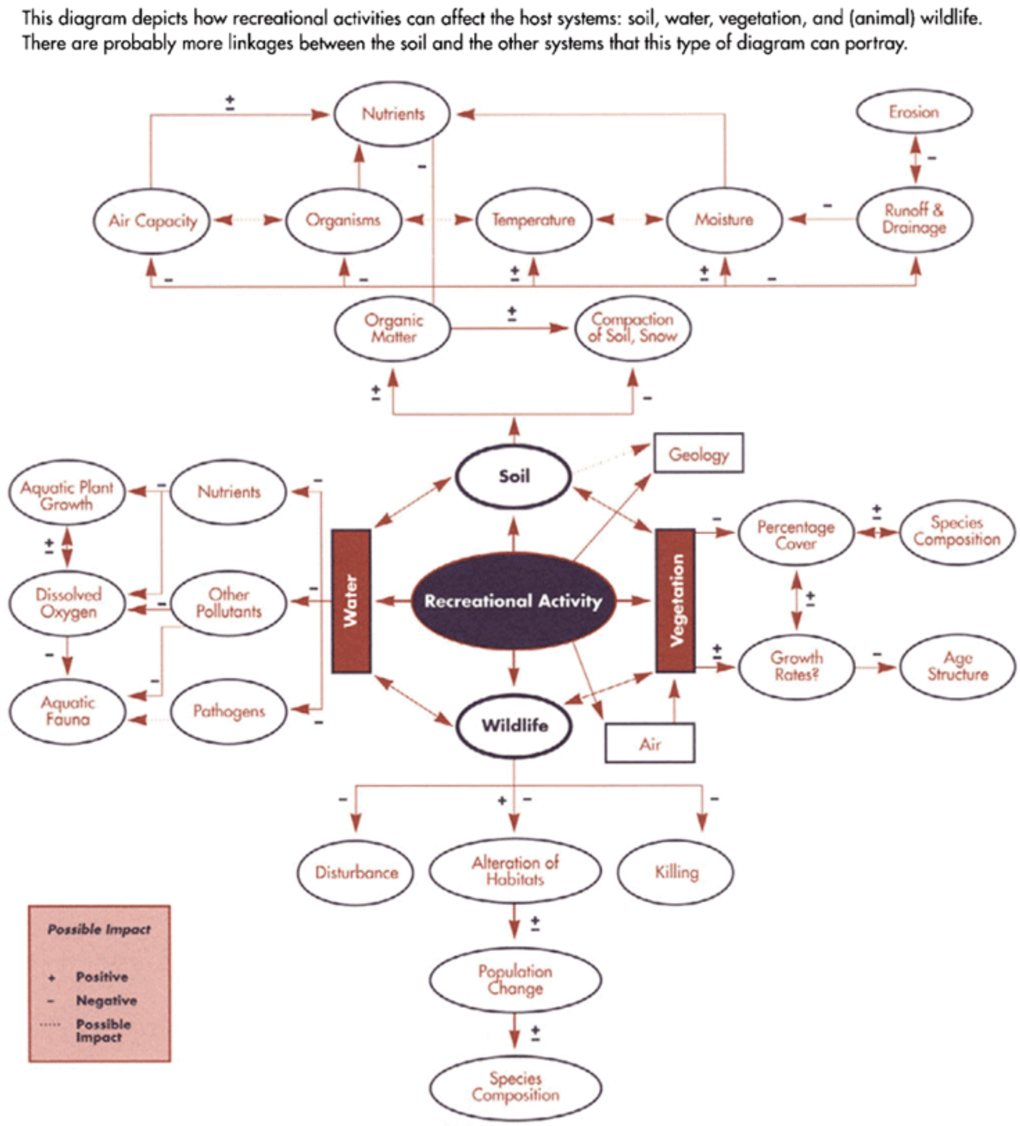


Figure 2. A framework for understanding the ecological effects of recreational activity (Adapted from Mathieson and Wall (1982), in ICLEI and IDRC 1996)

Although this framework provides a useful structure in which to discuss the effects of recreation, it is essential to note that there are connections, feedbacks and synergies between the categories. Ultimately, effects of disturbance must be addressed with an understanding of the cumulative and synergistic nature of their occurrence. A more recent conceptual model for understanding the ecological effects of outdoor recreation is presented in Figure 3. This model is congruent with the disturbance (agents of change) approach adopted for the current literature review.

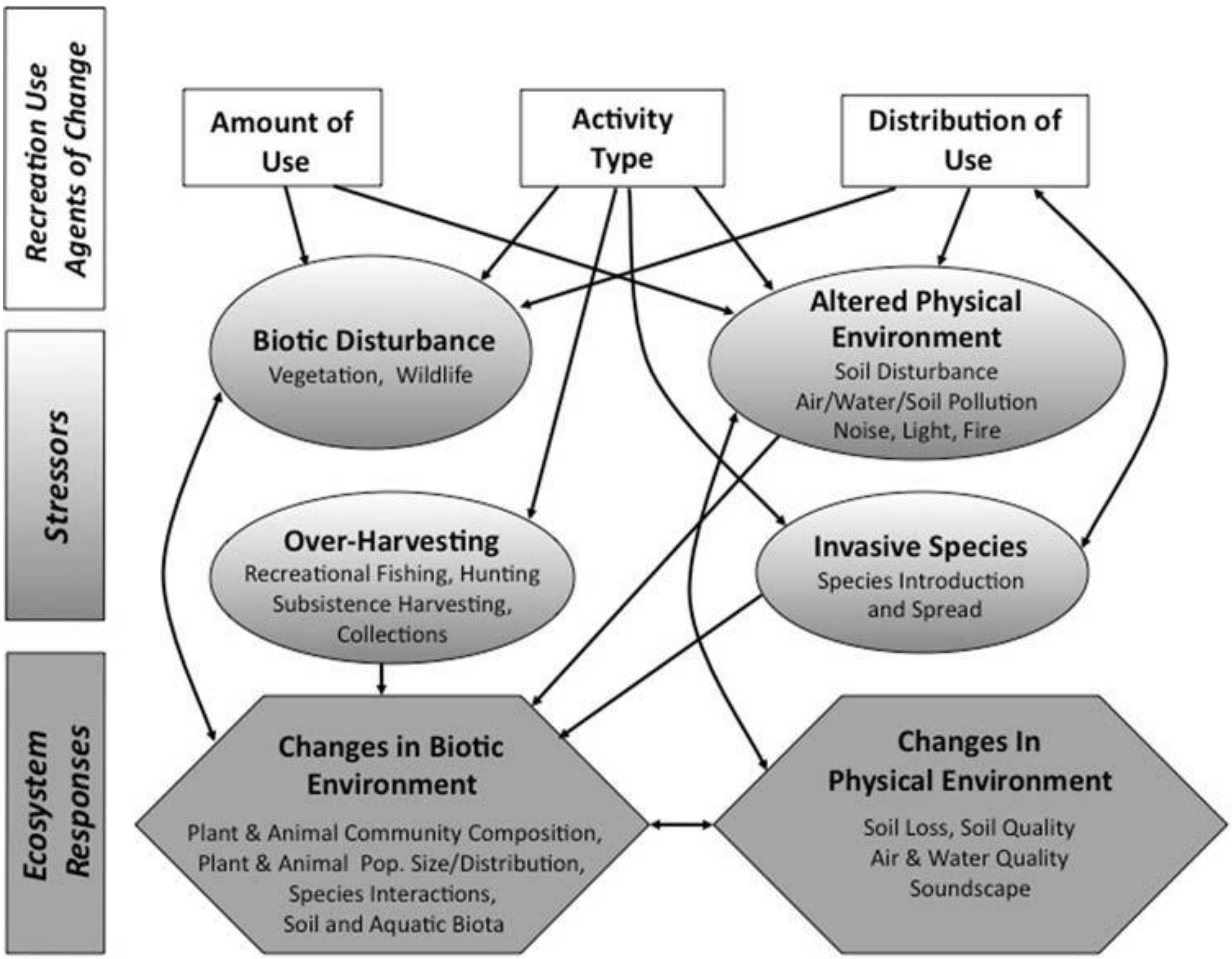
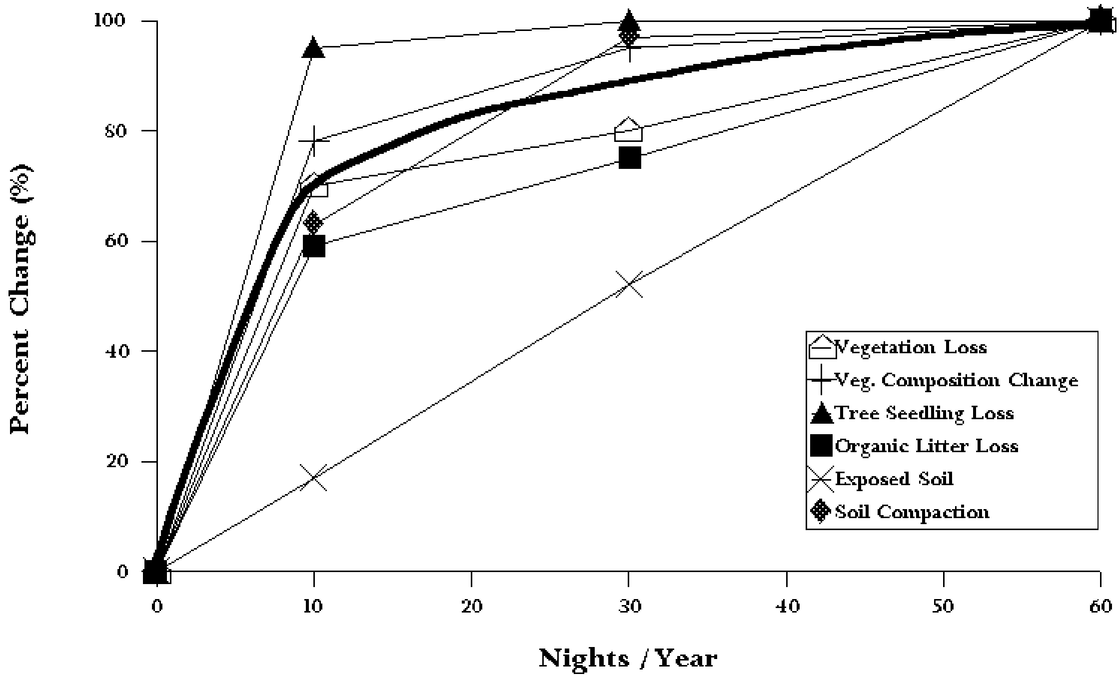


Figure 3. A conceptual model of ecological effects of outdoor recreation (Monz et al. 2010)

The study of recreation ecology involves considering activities that occur on land as well as in the air and water and below the ground. However, since we are concerned with effects of mountain biking, attention will be focused on terrestrial activities that happen in a similar setting (i.e., on trails).

A commonly noted characteristic of environmental effects related to nature-based recreation is referred to as the curvilinear use-impact relationship (Cessford 1995, Davies & Newsome 2009, Lathrop 2003, Liddle 1997, Marion & Wimpey 2007, Morlock et al. 2006, Pickering et al. 2010, Sprung 2004, Wilson & Seney 1994In fact, the "asymptotic nature of the use-impact relationship is among the most important generalization produced by recreation ecology" (Cole 2004, 111). In simple terms, the nonlinear nature of the use-effect relationship suggests that most of the ecological effect is generated in the first few uses. This phenomenon has been mostly observed in soils and vegetation responses to activity, and suggests that the majority of the environmental effect occurs when a trail is first developed or constructed – that very low levels of activity are responsible for creating a great deal of environmental degradation. Figure 4 provides an excellent example of this relationship showing that 60-70% of the vegetation loss, vegetation change, tree seedling loss, organic litter loss, and soil compaction occurred on campsites after only 10 camping nights in the Boundary Waters Canoe Area (Marion 1998). A generalized model of the curvilinear use-effect relationship is presented in Figure 5.



Note: Change is expressed as a percentage of change on high use sites. Thus, approximately 70% of the vegetation loss that occurs on campsites receiving 60+ nights/year has already occurred on campsites receiving 10 nights/year. The generalized curvilinear use-impact relationship is depicted by the thicker black line.

Figure 4. An example of the curvilinear use-effect relationship (Marion 1998, p. 188).

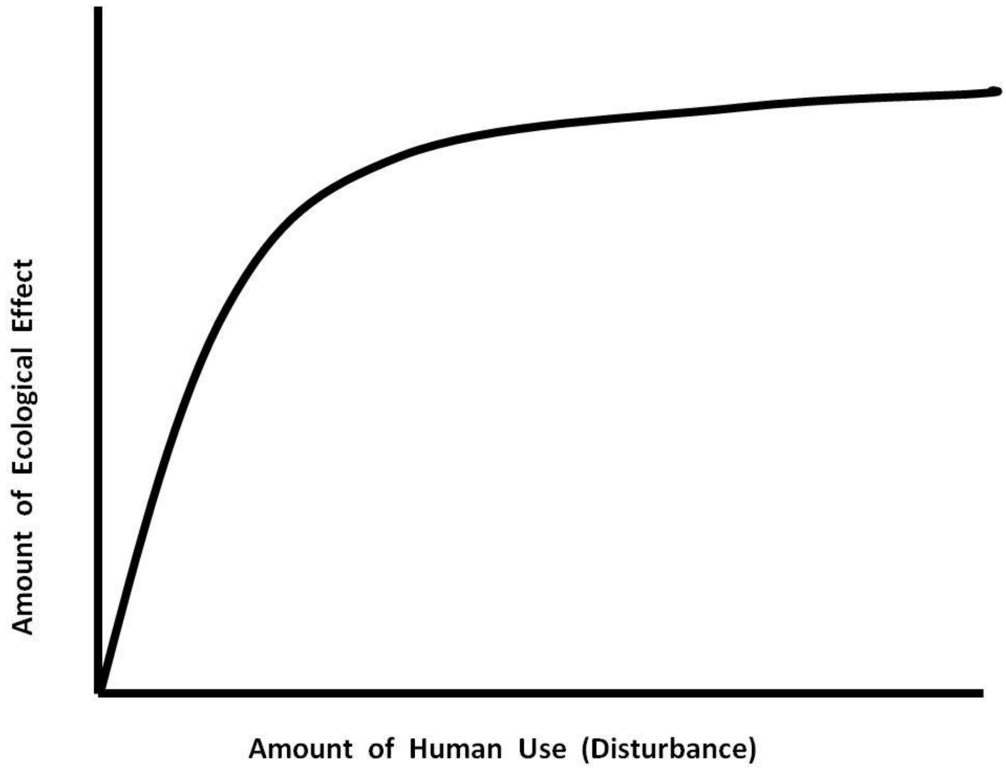


Figure 5. A generalized model of the curvilinear use-effect relationship.

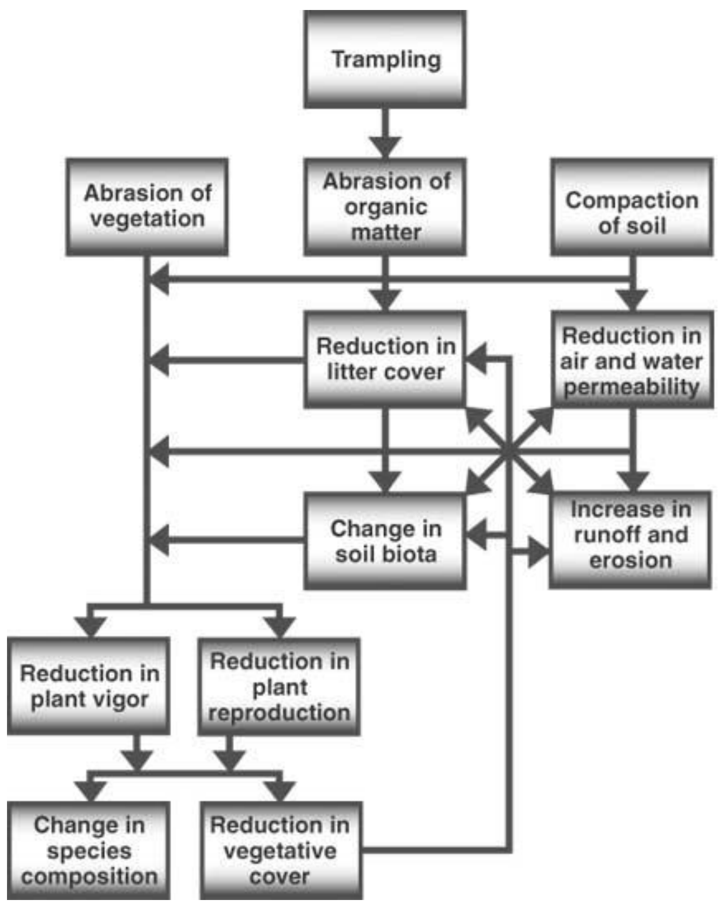


Figure 6. A conceptual model of trampling effects (Therrell et al. 2007)

Much of the research on this topic has come about as a result of the focus on 'trampling' as one of the primary effects of recreational activity in wildland settings. Figure 6 provides a conceptual model of trampling effects and the complexity of examining recreational effects. Incremental use, including use by new activities has been found to result in marginally less additional impact. This relationship makes comparative assessment of the impacts of one type of use over another problematic, as evidenced by many of the studies described in this report.

MOUNTAIN BIKING EFFECTS ON SOILS

There has been considerable research done on the effects of mountain biking on soils, in part because of the commonly held perception among other recreationists that mountain biking contributes disproportionately to soil degradation (Cessford 2003, Mann & Absher 2008, Mason & Leberman 2000). Research has mainly focused on quantifying erosion (created by shear forces) and compaction (created by normal forces) that result from mountain bike use and combine to create “tread incision” (Cessford 1995). Other concerns include water runoff and resulting sediment transport (erosion), and trail widening to avoid muddy or puddled areas (Pickering et al. 2010).

One of the most frequently cited studies of soil erosion was published by Wilson & Seney (1994), who applied a prescribed treatment (100 passes each with four different types of recreational activity, followed by simulated rainfall to assess soil erosion potential) to 108 sample plots along a trail network in Gallatin National Forest, Montana. The authors found that foot- and hoof-powered activities (hiking and horseback riding) had a greater erosive potential than did wheeled activities (off-road vehicles and mountain bikes). This effect was found to be especially pronounced when going downhill.

A similar experiment was conducted in a Provincial Park in southern Ontario, producing comparable results. Thurston & Reader (2001) applied mountain biking and hiking to adjacent, previously undisturbed plots at five different intensities, and recorded soil exposure. In her graduate work Thurston (1998) also measured soil compaction resulting from the two activities. The findings are consistent with the curvilinear use-impact relationship described above, and found no significant difference in the effects on soils of the two activities. A study that was conducted on a multi-use trail network in Kentucky and Tennessee found that of all types of trails, bike trails were found to be the narrowest, to have the least amount of soil loss, and to have the least incidence of running water on the trails (Marion & Olive 2006).

Many studies suggest that the site, situation, and landscape characteristics of a trail have more potential to effect soils than the actual nature of the activity. Trail steepness and orientation to terrain fall lines are both design factors that determine the extent of soil degradation; trails that are routed across slopes are less potentially erosive and have less water runoff potential than trails that run straight down slopes (Marion & Olive 2006, Cessford 1995, White et al. 2006). Landscape factors such as shade and moisture (Bjorkman 1998), and variability in composition of the soil (Marion & Olive 2006, Wilson & Seney 1994, Morlock et al. 2006) all have an effect on the erosion and compaction potential from mountain biking. Soil moisture has the potential to be beneficial to trail sustainability if it leads to increased cohesion (and hence reduced erosion), but if too much moisture is present in the right soils it can lead to increased compaction and channelling of water by the action of wheeling (Cessford 1995, Pickering et al. 2010). Marion & Olive (2006) reported that trails with heterogeneous soil composition (including rocks and gravel) are less susceptible to erosion than trails over more homogeneous, finer-grained soils. Goeft & Alder (2001) noted a seasonal effect on soil erosion – the effect was more pronounced during rainy seasons.

Researchers commonly indicated that mountain biking effects on soils are often the result of poor trail design, or of trails being used for activities outside of their originally intended purpose (Callahan 2008, Davies & Newsome 2009, White et al. 2006). Therefore, careful planning, maintenance (e.g., construction of water bars, berming or banking corners, ensuring proper drainage, avoiding steep slopes or loose erodible soils) and designation of trails to specific uses (and seasonal trail closures) may help mitigate against some of the more serious effects of mountain bike recreation to soils (Marion & Wimpey 2007, Goeft & Alder 2001). In discussions of best practices, researchers mentioned that cycling technique also influences the level of impact on soils, with braking/skidding and cutting switchbacks creating the most damage (Callahan 2008, Morlock et al. 2006, Marion & Wimpey 2007).

MOUNTAIN BIKING EFFECTS ON VEGETATION

Of the impacts to vegetation attributable to mountain biking and other recreational activities, vegetation trampling/removal is most commonly studied, followed by changes to biodiversity and facilitation of encroachment by invasive species.

Vegetation removal occurs commensurate with soil exposure, and is most prevalent when a trail is first constructed. The linkage between vegetation removal and soil compaction/erosion is so strong that the two phenomena are often studied in tandem (Bjorkman 1998, Goeft & Alder 2001, Pickering et al. 2010, Sun & Walsh 1998, Thurston & Reader 2001). The curvilinear impact-use relationship described above is well-supported in scientific studies of vegetation removal – for example, Thurston & Reader (2001) reported vegetation loss of up to 100% within two weeks of introduction of cycling (and hiking) activities on previously undisturbed sample plots. The majority of the deleterious effects is shown to occur during the first stages of trail development, and effects appear to be the same or similar regardless of the type(s) of recreational activity that are present (Bjorkman 1998, Pickering et al. 2010).

Studies on loss of plant diversity as a result of recreational activity have recently been reviewed by Pickering & Hill (2007). The authors found that recreational activity in Australia contributes appreciably to a loss in vegetation and native biodiversity, but that further quantitative study is required in order to assess the magnitude of the problem and to differentiate between effects of various types of recreational use. Although it is assumed that mountain biking provides a vector for the spread of invasive non-native plant species, we found no specific published studies addressing this issue. Likewise, Pickering and Mount (in press) found no studies examining mountain bikes as seed vectors.

Crealock (2002) undertook a comparative study of c-stratum vegetation adjacent to hiking, multi-use, and biking trails in coastal California, and found that different exotic and/or invasive species respond differently to varied types and intensities of disturbance. The study found that native plant cover decreased in areas more proximal to trails of all types, and generally that invasive species were more likely to be found immediately adjacent to trails of all types. Experimental treatment of simulated recreational use on sample plots indicated that some types of recreation favoured the spread of certain invasive species, while other types of activity created niches for different invasive species.

Depending on climate, plant physiology, and other landscapes, the response of vegetation to disturbance can be highly variable. Regarding all recreational effects on vegetation, caution must be exercised in applying findings from one ecological region directly to another. In one study of recreational effects on soil and vegetation in the southwestern US, White et al. (2006) interpret their findings according to Common Ecological Regions (CERs), and advocate that future broad-ranging recreation ecology studies apply a similar prescription.

MOUNTAIN BIKING EFFECTS ON WILDLIFE

Recreational activity can affect wildlife in three main ways (Liddle 1997):

1. Stress/Disturbance: Wildlife becomes aware of human activity, and respond by becoming stressed, altering their behaviour, avoiding (fleeing) areas of activity, or confronting/attacking humans. Such responses may detrimentally affect the fitness of an individual or a population. Displacement of animals by recreational disturbance may be short term (i.e., minutes or hours) or permanent.
2. Alteration of Habitat: The presence of human activity and/or infrastructure serves to remove or fragment habitat for wildlife, or can create artificial habitat which elicits change in population dynamics or encroachment of new species/populations.
3. Collision/Mortality: Wildlife is struck by humans or their vehicles, resulting in injury or death.

Clearly the sensitivity of each of these effects will vary widely between and even within species, and depending on the type of human activity that is taking place (Hammitt & Cole 1998, Bath & Enck 2003, Tempel et al. 2008, Knight & Gutzwiller 1995). The response of different species to different disturbance activities is largely a function of:

- Detection distance – the distance between humans and wildlife at which human presence is first detected.
- The sensitivity of a given species to human presence (including previous experience with human activity).
- The zone of influence associated with a given activity (determined by noise generated, speed of travel, intensity of use).
- Timing of the effect (e.g., life stage of the animal, breeding season, dispersal season, etc.).

The following is a sample of the available literature on the responses of wildlife to recreation generally, and mountain biking in particular.

“The sudden encounter is the most common situation associated with grizzly bear inflicted injury” (Herrero 1989). Mountain bikers are at particular risk of this type of encounter because the potential speed and relative silence of a biker may facilitate closer proximity to bears before being detected. Schmor (1999) interviewed 41 mountain bikers in the Calgary region who cycled in the Rocky Mountains. The responses indicated that 84% of survey participants had come within 50 m of a bear while mountain biking and 66% of the encounters clearly startled the bear. Herrero & Herrero (2000) studied incidence of conflict/interaction between humans and grizzly bears (*Ursus arctos horribilis*) along the Moraine Lake Highline Trail in Banff National Park. They found that, though intensity of use was much lower for mountain bikers than for hikers along this trail, mountain bikers accounted for a disproportionately high incidence of conflict with bears. Herrero and Herrero (2000) suggest that grizzly bears are more likely to attack if a human is closer than 50 m before being detected. The speed and relative silence of mountain bikes, especially when combined with environmental factors (e.g., dense vegetation, hilly terrain, sound of running water), likely contributed to mountain bikers approaching bears closer than 50m before being detected by the bear. Parks Canada instituted a requirement to travel in tight groups of at least six, which has reduced human-bear conflict in the area (Simic 2007).

Attempts to mitigate the relative silence of mountain bikes include the use of sound devices such as ‘bear bells’. Jope (1985) experimentally tested effect of bear bells on bear response to hikers in Glacier National Park. The results showed that a significantly greater number of bears responded by moving away from hikers with bear bells compared to hikers without bells. However, bear bells may not be as effective for mountain bikers as the sound may not be detected within the 50 m threshold distance. Schmor (1999) conducted field experiments to measure the sound of mountain bikers on uphill, downhill and flat sections of forested trail. The results indicated that increases in sound output over ambient sound levels ranged from 1 dB to 10.75 dB; very low levels that would only be detected in close proximity to the bicycle. Schmor (1999) repeated the trials using bear bells affixed to the handlebars of a mountain bike. Sound levels were measured at 2.5 dB to 12.75 dB over ambient sound levels with the greatest sound being produced over very rough terrain. Measurements indicated that the sound of a bear bell on a mountain bike was undetectable at a distance over 30 m. The author concludes that “bear bells are inadequate as a means of warning bears when used on mountain bikes” (p. 29). Schmor (1999) developed a conceptual design for a small, handle-bar mounted, ultrasonic sound device that was capable of providing a warning to bears at a distance of greater than 50 m while traveling at 20 km/hr. There is no indication that such a device has been tested or commercially produced as a means of warning wildlife of approaching mountain bikes.

Wildlife response to recreational activity is partly influenced by the nature and sequence of the sensory stimulus detection. The sensitivity to auditory, olfactory, visual and tactile stimuli is a function of the individual species characteristics. Recent advances in methods and monitoring technology have allowed researchers to collect data on sound (noise) and its potential disturbance to wildlife. The current literature review located only one study that focused on monitoring sounds of mountain biking and the potential effects on wildlife. However, a recent methods and review paper provides valuable information on collecting sound data for trail monitoring (Pater 2009). Monitoring the sounds associated with mountain biking (and other types of trail use) would be highly valuable for two reasons: 1) to quantitatively test the above assertion that mountain biking constitutes a unique type of disturbance due to the speed and relative silence of the activity thereby resulting in pronounced startle responses by wildlife, and 2) an increase in sound levels of only a few decibels has been shown to cause substantial changes in wildlife response (Grubb et al. 1998).

In an attempt to understand the comparative effects of different types of use, Taylor & Knight (2003) examined the response of bison (*Bison bison*), mule deer (*Odocoileus hemionus*), and pronghorn antelope (*Antilocapra americana*) to hikers and mountain bikers at Antelope Island State Park, Utah, by comparing alert distance, flight distance, and distance moved. The study did not reveal a significant difference between hikers and mountain bikers with respect to the reaction of any of the three species to their presence. A recent study by Naylor & Wisdom (2009), however, produced contrary results, albeit for a different species. In a controlled experiment, the behavioural changes by 13 female elk (*Cervus elaphus*) were monitored in response to four types of recreational disturbance: all-terrain vehicle riding, mountain biking, hiking, and horseback riding. Compared to control periods when elk spent most of their time feeding and resting, travel time increased in response to all recreational disturbance, but decreasing in the order listed above (i.e. ATV use eliciting the greatest increase in travel time, horseback riding eliciting the least). Both mountain biking and hiking activities were found to significantly reduce resting time for elk.

Avian species have been studied extensively regarding their response to recreation and other human disturbance. Miller & Knight (1998) studied responses of multiple species of birds to recreational activities (including mountain biking) along a trail network in Boulder, Colorado. They found that the presence of trails and activity along them (types or intensities of use were not compared) led to an alteration of species composition in both ponderosa pine forest and open mixed grassland ecosystems. Specifically, generalist species such as American Robins (*Turdus migratorius*) were found to be more common along recreational trails. Nests for all species were less likely to occur and more susceptible to predation in areas proximal to trails. In a study conducted in the Black Forest in southwestern Germany (Thiel et al. 2008), Collared Capercaillie (*Tetrao urogallus*) were observed before and during ski season, and were found to experience elevated levels of stress during periods of increased human activity. Blumstein et al. (2005) gathered and analyzed all available data published between 1980 and 2003, and modeled behaviour of 150 avian species in response to disturbance by human recreation (specifically hiking). The model suggests that detection distance is a key factor explaining inter-specific variation in response to human disturbance and that, in general, larger birds detect human presence at greater distance than smaller birds. Whitfield et al. (2008) reviewed the literature for alert distance and flight initiation distance for 26 bird species of interest in Scotland. They found the literature wanting in empirical data to justify the establishment of buffer zones. Although expert opinion may provide the best available information, Whitfield et al. (2008) clearly demonstrate that such information be employed only as “a stopgap until empirical research has been conducted” (p. 2715).

The alteration and fragmentation of habitat that results from construction of linear features like trails and the resulting effect on wildlife that depend on that habitat is a topic of current concern in the literature. The majority of research has been conducted in a site-specific manner and over short periods of time. However, "[n]umerous studies assess the short-term responses of individual animals to recreational disturbances.... But little is known about whether such disturbances have significant long-term impacts on... wildlife" (Cole 2004, 109). Thiel *et* al. (2008) as discussed above, discovered that Capercaillie abandoned otherwise ideal habitat that was located in areas adjacent to busy ski trails. Preisler *et* al. (2006) studied the response of elk (*Cervus elaphus* L.) to all-terrain vehicle use in a controlled-access area, and found that once displaced from an area by human activity, they habitually avoided those areas regardless of the attractiveness of the habitat within the zone of human influence.

Incidences of direct mountain-bike caused wildlife mortality are rare, the most frequent casualties being insects. Since mortality or injury from collision only becomes a concern with recreational activities that are largely prohibited in National Parks, further discussion of this effect is not warranted.

MOUNTAIN BIKING EFFECTS ON WATER

This review discovered no published research related to the effects of mountain biking on water resources.

Hammitt & Cole (1995) provide a good overview of water quality concerns that relate to outdoor recreation; these include:

- Introduction of pollutants or pathogens through careless disposal of human waste (see also Suk *et* al. 1987).
- Alteration to the nutrient content of water courses and water bodies, resulting in changes to aquatic biota.
- Increased sedimentation and turbidity resulting from activities that occur in or adjacent to water.

Cole and Landres (1996) indicate that "our understanding of recreational impacts on aquatic systems in wilderness is so rudimentary that a simple assessment of the prevalence and intensity of such impacts is a top research priority" (p. 171).

RESULTS AND KNOWLEDGE GAPS

This review of the literature has identified some important gaps in the current state of knowledge regarding the environmental effects associated with mountain biking.

The vast majority of research that has been conducted on this subject addresses the more "traditional" disciplines of mountain biking – that is, cross-country or trail riding. These are activities that occur largely on infrastructure (trails and associated features) that already exist, and that were likely originally developed for some other purpose. The fact that cross-country mountain biking often shares trails with other forms of recreation like hiking and horseback riding facilitates the comparison of these uses and their resulting environmental effects. Although the objective of this study was to compare documented environmental effects among the different disciplines of mountain biking, such a comparison is currently impossible since there is no scientific literature to support it.

It is important to recognize that any form of recreational activity involves some degree of environmental effect on the soils, vegetation, wildlife and water of the landscape it which it takes place. Some clear conclusions can be drawn from the literature presented in this report:

- The science strongly indicates a curvilinear relationship between use and environmental effects; regardless of the type of activity that occurs, the most detrimental environmental effects (especially to soils and vegetation) occurs when a trail is first constructed.
- Though the effects on soil of wheeled travel are notably different than those of recreationists travelling on feet or hooves, it seems difficult to determine whether one mode of travel is universally more damaging than the other. The amount of erosion, compaction, and sediment damage that occurs is highly variable and depends on:
    - The ecosystem and resulting soil characteristics in which the activity is taking place.
    - The amount of moisture in or on the soil.
    - The steepness of the slope, its orientation in relation to the fall line, and the direction of travel (ascending or descending) of the user.
    - The behaviour of the user (whether or not best practices are known/applied).
    - The design of the trail (including mitigative infrastructure) and the recreational use for which it is intended.
- Effects on vegetation are highly commensurate with effects on soil, and are similarly difficult to assess universally in terms of types of recreation that are comparatively more or less detrimental. Vegetation is removed from a trail as part of its design, and activities that follow trails should not appreciably increase the amount of vegetation that has been removed. Certain invasive species seem to react favourably to the presence of mountain biking, but others prefer the vectors provided by other activities.
- There is support in the literature for the hypothesis that the effects on some species of wildlife are more pronounced with mountain bikes than they are with other forms of recreation (primarily related to the 'sudden encounter' effect), but again these effects are highly dependent on the species being considered and other factors.
- Recreation ecology, similar to other kinds of field ecology, is fraught with the challenges of conducting statistically valid research. "Most studies are deficient in any number of ways: they may be too short in duration, not have adequate controls or replications, be anecdotal in nature, or have too many potentially confounding variables" (Knight and Cole 1995).

Some gaps in the research are also evident from our review of the literature. Some of the most important knowledge gaps include:

- To date, there have been no documented interdisciplinary studies of the environmental effects associated with mountain biking.
- Very little has been studied of the recreational ecology of mountain bikes in the Canadian context. Since many of the environmental effects are known to vary according to regional geophysical traits, applying research carried out in other biomes and landscapes may be problematic.
- No specific research has been published on the water-related environmental effects of mountain biking.
- Some more focused study of the effects of mountain biking on wildlife would be of benefit.
- Existing research focuses mainly on the type of recreational activity with little or no emphasis on the timing, intensity, duration and spatial distribution of the activity.
- There is a tremendous need for research that addresses the cumulative effects of human recreational activity in protected areas. This includes the need to identify thresholds associated with numbers, timing and distribution of use.

DISCUSSION – RESEARCH QUESTIONS, MANAGEMENT IMPLICATIONS

In order to address the knowledge gaps identified in the previous section, we propose some potential questions to be answered by future research.

Since the different disciplines of mountain biking involve different equipment, infrastructure, and terrain, they can be expected to result in differing degrees of environmental effects. Some research questions that may be asked to aid in assessing these differences include:

- What are the effects to soils and vegetation of off-trail riding?
- Given that freeride and downhill bikes are generally heavier but also have larger, lower-volume tires, and also given that freeride and downhill disciplines involve more descending and less climbing, what are the comparative effects on soil erosion of these types of bicycles versus cross-country bicycles?
- Since speed and range of detectability are two main determinants of human-animal conflict, and since freeride and downhill mountain biking potentially involve travelling more quietly and quickly, are there increased risks of conflict associated with these forms of mountain biking over others?
- What are the effects related to construction of mountain biking infrastructure such as log bridges, ramps, and berms? How do the potentially negative effects (removal of vegetation including logs for construction purposes, shifting of soils and vegetation to alter landforms, etc.) weigh against the potential benefits (e.g. bridges elevate cyclists off the ground, reducing potential effects on soil and vegetation)?

With respect to the lack of a Canadian perspective in the current body of knowledge on this subject, obviously a nation-wide systematic study would be impractical. Instead we recommend that managers consider how the Canadian context differs from those of other studies, and consider some site-specific assessment of potential effects.

Similarly, concerns regarding the interaction between mountain bikers and wildlife are difficult to generalize on a national level – potential threats to critical species must be assessed at a local level and on a case-by-case basis. An easily accessible means of reporting human-wildlife interaction might assist in building a longitudinal data set which could be analyzed to identify problem areas and better focus research efforts.

Potential research questions related to effects of mountain biking on water resources might include:

- How do stream crossings by mountain bikes affect water quality, aquatic habitat, etc.?
- Are their additional effects (compared to other recreational activities) from mountain biking associated with stream-side or riparian areas?

The human dimensions research on the subject of the mountain biking community, public perceptions of this culture, and conflict between different user groups is extensive and growing. The results of many surveys (Cessford 2003, Chavez et al. 1993, Janowsky et al. 2003, Mann & Absher 2008, Mason & Leberman 2000) demonstrate a gap between the perception and reality of environmental effects associated with mountain biking, and suggest the need for management of not only the effects but the perception thereof as well.

To further complicate matters, there may be a perception-reality conflict among the mountain biking community as well. Two separate user preference studies (Bowker & English 2002 and Symmonds et al. 2000) reported conflicting results – surveyed mountain bikers reported a preference for technically challenging trails with loose rocks, exposed roots, and rutting, but also stated a preference for minimized environmental degradation. Results such as these suggest that some education on cycling best practices may be needed.

This leads to a grey area between natural and social science in the management of recreation in public spaces – it may be that in order to manage for minimization of negative environmental effects, some social intervention (e.g., education in best practices, user conflict resolution workshops, etc.) is necessary.

Another management concern may be related to designing trails for appropriate use. There are some design practices that make sense for all recreational uses, but others that are more use-specific. We speculate that very few trails in National Parks have been designed specifically with mountain biking and the minimization of associated environmental effects in mind – moreover, the majority of mountain biking currently occurs on old fire roads, hiking, or pack trails. Trail creation, maintenance, modification or access limitation that recognizes the different effects and designs to minimize these effects and promote best practices should be considered (Flickinger 1994). This gives rise to a suite of design-related research questions:

- If we recognize, for example, that erosional effects are most severe when cyclists climb steep hills and hikers descend steep hills, what reductions to erosion can we expect if we limit hiking to trails with minimal steep descents, and cycling to trails with minimal steep climbs?

- Can a reduction in environmental effects be achieved by offering (or mandating) best practice education programs for trail users?
- Do seasonal closures have the potential to reduce environmental effects?
- Can designing trails with mountain biking in mind (e.g., banking corners, surface treatment, minimizing fall line descents, ensuring proper trail drainage, etc.) tangibly reduce environmental damage?

There is potential to use spatially explicit modeling techniques to evaluate the potential benefits of these types of management practices (e.g. Itami et al. 2003).

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APPENDIX A - ANNOTATED BIBLIOGRAPHY

References are categorized by broad subject area. Grey text denotes grey literature sources. Annotations focus on any information that documents contain relating to ecological impacts.

Case Studies – Ecological

Bjorkman, Alan Wayne. 1998. Biophysical Impacts on and User Interactions with Mountain Bicycle Off-Road Corridors. PhD Thesis. University of Wisconsin – Madison.

A study of ecological impacts (focusing on soil and vegetation) of mountain bike trail use in the Kettle Moraine State Forest in southeastern Wisconsin. Bjorkman found that slope, shade and type surface treatment (and interestingly not intensity of use) were the strongest factors determining width of trampled vegetation. The dissertation also includes a sociography of MTB trail users, providing insight into the efficacy of different potential mitigative approaches.

Callahan, Joshua. 2008. Erosion and Trail Building: A Case Study of the East Tennessee State University Trail System. MSc Thesis. East Tennessee State University.

A study of the erosion associated with increased MTB use on a multi-use trail system at East Tennesse State University in Johnson City, Tennessee. More of a literature review with subsequent recommendations than a focused research project – no data collected on rates of erosion on ETSU trail network.

Cessford, Gordon R. 1995. Off-Road Impacts of Mountain Bikes – A Review and Discussion. New Zealand Department of Conservation. Science and Research Series, no.92. 41pp.

A comprehensive (current to 1995) review of existing literature on ecological and sociological impacts related to mountain bike trail use. Author asserts that there is a gap between perception and reality when it comes to impacts of mountain biking as compared to other activities.

Chiu, Luke, & Lorne Kriwoken. 2003. Managing Recreational Mountain Biking in Wellington Park, Tasmania, Australia. Annals of Leisure Research vol.6 no.4, pp.339-361.

This paper includes both a literature review of ecological and sociological impacts of MTB use, and also a focused study designed to determine the specific impacts of MTB use in Wellington Park. Specifically looks at comparing impacts related to MTB versus other uses. Ecological study addresses impact on soil impaction and erosion, with six main hypotheses (listed on p.349) related to trail site characteristics. Data collection was through a linear elevation measuring instrument. Sociological data gathered through a trail user survey.

Davies, Claire, & David Newsome. 2009. Mountain Bike Activity in Natural Areas: Impacts, Assessment and Implications for Management – A Case Study from John Forrest National Park, Western Australia. CRC for Sustainable Tourism Pty, Australia.

Literature Review on the impacts of MTB use, both ecological and sociological. Ecological impacts seem to focus on trail erosion. Aside from general impact assessment from literature review, includes a biophysical assessment of soil alteration/damage within John Forrest National Park near Perth Australia – use of GPS to map and enumerate informal trail network, constructed features, etc. Differentiates between different 5 types of MTB users. Also contains a section on proposed management strategies to mitigate against trail erosion/degradation.

Ferguson, Krystyn. June 2008. The Destructive Impact of Mountain Biking on Forested Landscapes. The Environmentalist vol.28 no.2, pp.67-68.

An editorial, written by a restoration ecology student, describing observed detrimental impacts of freeride MTB use on soils and native vegetation in the Natchez Hills forest tract near Kitchener, Ontario. Not a scientific study so much as an anecdotal editorial based on personal experience and observation.

Goeft, Ute, & Jackie Alder. 2001. Sustainable Mountain Biking: A Case Study from the Southwest of Western Australia. Journal of Sustainable Tourism vol.9 no.3, pp.193-211.

The authors report on a two-pronged study assessing mountain bike use in southwestern Australia. The first study focused on determining ecological impacts (soil and vegetation) through a systematic survey; the second assessed sociological impacts through a rider survey. The physical study assessed soil erosion and compaction as well as vegetation composition and removal (trail widening) on sample plots along both new and old trails with both open and limited access. Study results suggest suggest that trail erosion rates are determined by seasonality, slope, and age of trail.

Herrero, Jake, & Stephen Herrero. 2000. Management Options for the Moraine Lake Highline Trail: Grizzly Bears and Cyclists. Parks Canada.

A study of the reported incidences of bear-human conflicts along the Moraine Lake Highline Trail near Lake Louise in Banff National Park. The authors found that, though intensity of use is much lower for mountain bikers than for hikers along this trail, mountain bikers accounted for a disproportionately high incidence of conflict with grizzly bears. Furthermore, mountain bikers are more likely to be attacked, since they travel more swiftly and silently and are hence more likely to surprise a bear (bears demonstrate a greater propensity to attack when they first become aware of human presence at a distance of less than 50m).

Lathrop, Jason. 2003. Ecological Impacts of Mountain Biking: A Critical Literature Review. Wildlands CPR Report. 11pp.

An assessment of current (2003) literature on the ecological impacts of mountain biking, in terms of trampling (effects on vegetation), erosion (effects on soils), and wildlife disturbance. His is not a peer-reviewed article and the author appears to have an anti-MTB prejudice. Conclusions are that there is little documented difference in impact on vegetation between hiking and MTB use, that there is support for the generic “curvilinear response” of soils (most of the damage occurring during of immediately following construction) to trail construction and use, that soil damage may be less significant with wheeled use than with foot-based activities, and that though there is an intuitive

increase in human-wildlife conflict potential with mountain biking versus other activities, this has not been studied extensively.

Marion, Jeff, & Jeremy Wimpey. 2007. Environmental Impacts of Mountain Biking: Science Review and Best Practices. In Managing Mountain Biking: IMBA's Guide to Providing Great Riding.

A literature review of ecological effects associated with mountain biking, subdivided into impacts on vegetation, soil, water and wildlife. The review lists general recreation ecology studies as well as MTB-specific and comparative studies, and also suggests mitigative management practices that could serve to minimize disturbance by mountain bikers. The authors conclude that careful management of mountain biking and other recreation (designation of specific trails for specific uses, use-specific and ecologically conscientious trail design, user education, seasonal closures, etc.) can effectively minimize the environmental impacts associated with mountain bike use. IMBA endorsement suggests potential for some prejudice.

Marion, Jeffrey L., & Nate Olive. 2006. Assessing and Understanding Trail Degradation: Results from Big South Fork National River and Recreation Area. USGS Patuxent Wildlife Research Center/National Park Service Research Report. 84pp.

This paper documents a ecological impact study that was conducted on a multi-use trail network in Big South Fork National River and Recreation Area, located on the Cumberalnd Plateau in Kentucky and Tennessee. The author includes a literature review and description of the research project, it's findings, and some management recommendations. 24% of the trail network was sampled, stratified by use (hiking, mountain biking, OHV, horseback riding, and mixed use trails. Data was collected related to soil erosion, exposure of roots, widening/re-routing of trails (secondary tracks), wet (muddy) soil, and running water on trails. Site characteristics such as vegetation type, topography, soils, and infrastructure were also recorded. Of all use types, bike trails were found to be the narrowest, to have the least amount of soil loss, and to have the least (0) incidence of running water on the trails.

Miller, Scott G., & Richard L. Knight. 1998. Influence of Recreational Trails on Breeding Bird Communities. Department of Fishery and Wildlife Biology, Colorado State University. 31pp.

The influence of proximity recreational trails on behavioural ecology of breeding birds was examined in two ecosystems (ponderosa pine forest containing 29 bird species, and mixed-grass prairie containing 13 bird species)in Boulder, Colorado. The authors found that the presence of trails led to an alteration of species composition in both ecosystems, favouring an increase in generalist avian species. In grassland areas, birds were less likely to nest near trails; in both ecosystems the presence of trails was found to result in an increased rate of nest predation. Though mountain bike use is not assessed independent of other uses, it is one of the documented uses on the trail network.

Morlock, Phil, Dave D. White, Don Applegate, & Pam Foti. 2006. Planning & Managing Environmentally Friendly Mountain Bike Trails – Ecological Impacts – Managing for Future Generations – Resources. 59pp.

A guide to trail construction and maintenance that considers environmental impacts. Ecological/ biophysical impacts are assessed both generally through a literature review, and specifically through three separate studies conducted in the southwestern US (collectively referred to as the Southwest Mountain Bike Study). In the first study, biophysical characteristics of 31 MTB trails were assessed. The trails were located in 5 distinct ecological regions, and the authors emphasize the need to compare ecological impact studies within Common Ecological Regions (CERs). The second study assesses the effectiveness of a management policy implemented in the Lake Tahoe Basin. The third study examined the pre- and post-race ecological conditions of the site of an annual MTB race in Arizona. Main conclusions of the report are that mountain biking has an ecological impact, but that this impact is mitigable with proper trail design, trail use, and management; that impacts of mountain bike use must be assessed within CERs; and that more empirical studies are required in order to determine the impacts and suggested management strategies within different ecoregions.

Naylor, Leslie M., Michael J. Wisdom, & Robert G. Anthony. 2009. Behavioural Responses of North American Elk to Recreational Activity. Journal of Wildlife Management, vol.73 no.3, pp.328-338.

The authors assess the behavioral changes demonstrated by 13 female elk (*Cervus elaphus*) in response to four types of recreational disturbance: all-terrain vehicle riding, mountain biking, hiking, and horseback riding. Compared to control periods when elk spent most of their time feeding and resting, travel time increased in response to all recreational disturbance, but decreasing in the order listed above. Observed increases were highest during mornings. Both mountain biking and hiking are demonstrated to reduce resting time for elk. Study area is Starkey Experimental Forest and Range in northeast Oregon.

Newsome, David and Claire Davies. 2009. A case study in estimating the area of informal trail development and associated impacts caused by mountain bike activity in John Forrest National Park, Western Australia. Journal of Ecotourism 8(3):237-253.

The authors develop and test a rapid assessment tool for evaluating the effects of mountain biking in natural areas. The emphasis is on the spatial identification of new trails and modifications to existing trails.

Pickering, Catherine Marina, Wendy Hill, David Newsome, & Yu-Fai Leung. 2010. Comparing Hiking, Mountain Biking, and Horse Riding Impacts on Vegetation and Soils in Australia and the United States of America. Journal of Environmental Management 91(3):551-562.

A systematic, comprehensive review of all known empirical studies from the US and Australia that have sought to identify and/or compare the effects of hiking, mountain biking, and horseback riding on soils and vegetation. A very good and current synopsis of known literature related to soils and vegetation recreation ecology. Impacts associated with each type of use are described individually, and there is also a section describing the findings of comparative, cross-use studies.

Pickering, Catherine Marina, & Wendy Hill. 2007. Impacts of Recreation and Tourism on Plant Biodiversity and Vegetation in Protected Areas in Australia. Journal of Environmental Management, vol.85, pp.791-800.

A systematic literature review of the ecological impacts of outdoor recreation in Autralia, specifically related to vegetation. Along with denudation of landscapes, the research also points to indirect impacts such as addition of nutrients (human waste), creation of vectors for invasive plants, and the introduction of pathogens (e.g. root rot). The authors point to one study that showed a higher degree of erosion attributed to mountain bikes than to high-use hiking trails. Mostly a general treatment of recreation ecology, but some comparative or single-use research is cited.

Preisler, Haiganoush K., Alan A. Ager, & Michael J. Wisdom. 2006. Statistical Methods for Analysing Responses of Wildlife to Human Disturbance. Journal of Applied Ecology, vol. 43, pp.164-172.

A controlled study of the response of Rocky Mountain elk (*Cervus elaphus* L.) to all-terrain vehicle use along a 32km trail inside a 1453ha elk enclosure. Human movement was recorded using GPS, and elk movement was recorded by telemetry. The methods used suggest that elk respond (with flight/avoidance) to human presence upwards of 1km distant. Furthermore, elk displayed avoidance of the trail even when no ATVs were present.

Schmor, Mathew Robert. 1999. An exploration into bear deterrents, as related to mountain biking, and the design of an ultrasonic bear warning device. Masters Degree Project, Faculty of Environmental Design, University of Calgary.

A masters degree projected conducted to evaluate the noise produced by mountain biking. This is one of the only studies to quantitatively assess the sounds produced by mountain biking. The author tests the effectiveness of bear bells and concludes that they are ineffective in providing adequate warning to bears on trails. A design for an ultrasonic warning device is developed, but not tested.

Simic, Jovan. 2007. Moraine Lake – 2007 Group Access Study: Visitor Experience, Compliance and Awareness. Parks Canada. 15pp.

Partly as a result of Herrero and Herrero's research (see above), Banff National Park implemented a minimum group size of six (subsequently reduced to four) in the Moraine Lake area of Banff National Park. The author finds that a reduction in minimum group size from six to four increased both compliance and visitor satisfaction, while keeping incidence of human-bear conflicts well below historical levels.

Sprung, Gary. 2004. Natural Resource Impacts of Mountain Biking – A Summary of Scientific Studies that Compare Mountain Biking to Other Forms of Trail Travel. In Trail Solutions: IMBA's Guide to Building Sweet Singletrack.

An annotated bibliography or research on the ecological impacts of mountain biking. The author clearly displays some pro-bike prejudice in the discussion sections, but regardless there are some good resources cited, especially regarding impacts on wildlife.

Taylor, Audrey R., & Richard L. Knight. 2003.Wildlife Responses to Recreation and Associated Visitor Perceptions. Ecological Applications, vol.13 no.4, pp951-963.

An attempt to address the gap in knowledge regarding the response of wildlife to mountain bike use as compared to other types of recreation. The study examined the response of bison (*Bison bison*), mule deer (*Odocoileus hemionus*), and pronghorn antelope (*Antilocapra americana*) to hikers and mountain bikers at Antelope Island State Park, Utah, by comparing alert distance, flight distance, and distance moved. The study did not reveal a significant difference between hikers and mountain bikers with respect to the reaction of any of the three species to their presence. The zone of human influence within the study area constituted 7% of the total area of the island. The study also surveyed recreational users to determine their perceived impact on wildlife, and found a strong propensity for users to blame other user groups for having a greater impact on wildlife.

Thiel, Dominik, Susanne Jenni-Eiermann, Veronika Braunisch, Rupert Palme, & Lukas Jenni. 2008. Ski Tourism Effects Habitat Use and Evokes a Physiological Stress Response in Capercaille *Tetrao urogallus*: A New Methodological Approach. Journal of Applied Ecology, vol.45, pp.845-853.

The authors radio-tracked and collected fecal samples of capercaille in the Black Forest of Germany, and compared levels of corticosterone metabolites (indicators of stress) detected in feces before and during ski season. The results indicate that increased intensity of use is a stressor to capercaille; other research indicated that the birds avoided high-intensity human use areas that were otherwise ideal habitat.

Thurston, Eden, & Richard J Reader. 2001. Impacts of Experimentally Applied Mountain Biking and Hiking on Vegetation and Soil of a Deciduous Forest. Environmental Management, vol.27 no.3, pp.397-409.

The authors constructed an experiment wherein mountain biking and hiking were applied to adjacent, previously undisturbed sample plots in Boyne Valley Provincial Park in southern Ontario. Uses were systematically applied at five different intensities, and changes in plant stem density, species richness, and soil exposure were recorded before, shortly after, and a year after treatment. The findings support the well-documented curvilinear response of soil and vegetation to disturbance, and found little appreciable difference in the measured characteristics to the two different types of recreational use. In general, recreational use of deciduous understory resulted in 100% removal of vegetation, and up to 54% increase in exposed soil.

Thurston, Eden. 1998. An Experimental Examination of the Impacts of Hiking and Mountain Biking on Deciduous Forest Vegetation and Soil. PhD Thesis, University of Guelph. 150pp.

The PhD dissertation from which the previous citation originated. Aside from the research described above, the author also measured changes in soil impaction (trail depth), and found no appreciable difference between mountain bike and hiking applications, and indeed very little change in trail depth for the different intensities of use applied in the study.

White, Dave D., M. Troy Waskey, Grant P. Brodehl, & Pamela E. Foti. 2006. A Comparitive Study of Impacts to Mountain Bike Trails in Five Common Ecological Regions of the Southwestern U.S. Journal of Park and Recreation Administration, vol.24 no.2, pp.21-41.

A peer-reviewed article on the Southwest Mountain Bike Study described in the IMBA trail guide – see Morlock et al citation above. Analysis was done on soil erosion characteristics (trail incision (depth) and width) at sample plots on 163 miles of MTB trails over 5 distinct ecological regions in the southwestern US. The authors found that degree of erosion varied between ecological region and attributed this variability to characteristics of soil and vegetation typical to the local landscape. Soil erosion increased with steeper slopes for all ecoregions studied. Intensity/level of use was neither accounted nor controlled for in the study.

Wilson, John P., & Joseph P. Seney. 1994. Erosional Impact of Hikers, Horses, Motorcycles, and Off-Road Bicycles on Mountain Trails in Montana. Mountain Research and Development, vol.14 no.1, pp.77-88.

A systematic study that compared the erosive (water runoff and sediment yield) impacts associated with hiking, horseback riding, motorcycles, and mountain bikes at 108 sample plots along a trail network in Gallatin National Forest, Montana. The main findings of this study suggest that foot-powered use (horses and hikers) create more erosive potential than wheeled forms of recreation.

Case Studies – Sociological

Bowker, JM and Donald BK English. 2002. Mountain Biking at Tsali: An Assessment of Users, Preferences, Conflicts, and Management Alternatives. USDA Forest Service, Athens, GA.

The authors, Social Scientist for the USDA Forest Service, report on the results of a 13-month survey of MTB trail users in the Tsali Recreation Area in western North Carolina's Nantahala National Forest. Findings focus on the demographics, behavior, trip profile, and attitude towards user fees. Some brief mention (pp.10-11) of ecology-related trail management (horse/bike rotation, trail surfacing, etc.). Survey questionnaires included as Appendix.

Cessford, Gordon. 2003. Perception and Reality of Conflict: Walkers and Mountain Bikes on the Queen Charlotte Track in New Zealand. Journal for Nature Conservation, vol.11, pp.310-316.

Also in Cessford, Gordon R. 2002. Perception and Reality of Conflict: Walkers and Mountain Bikes on the Queen Charlotte Track in New Zealand. In Arnberger, A.,C. Brandenburg, & A. Muhar (eds.). Monitoring and Management of Visitor Flows in Recreational and Protected Areas; Proceedings of the Conference held at Bodenkultur University, Vienna. pp.102-108.

Following a brief review of the study of ecological and sociological impacts related to mountain biking, the author reports results of a survey of 370 hikers on a trail in New Zealand that had recently been opened to cyclists. A distinct difference was noted between the opinions of hikers who had actually encountered a mountain biker (generally positive towards bikes and cyclists) and those who had not (generally more negative).

Chavez, Deborah J., Patricia L. Winter, & John M. Baas. 1993. Recreational Mountain Biking: A Management Perspective. Journal of Park and Recreation Administration vol.11 no.3, pp.29-36.

Results of a survey of 40 recreational managers from the USDA Forest Service and the USDI Bureau of Land Management. The survey focused on intensity of use and inter-use conflict, but also recorded qualitative information on trail degradation related to mountain bike use.

Janowsky, Dagmar V., & Gero Becker. 2003. Characteristics and Needs of Different User Groups in the Urban Forest of Stuttgart. Journal for Nature Conservation, vol.11, pp.251-259.

A combination of video capturing, expert interviews, and GIS modeling was used to profile different user groups of an urban forest in Stuttgart, Germany, and to identify times and places with the highest potential for user conflict. Optimal solutions also sought to minimize environmental damage from human activity.

Mann, Carsten, & James D. Absher. 2008. Recreation Conflict Potential and Management Implications in the Northern/Central Black Forest nature Park. Journal of Environmental Planning and Management vol.51 no.3, pp.363-380.

A quantitative study that assesses conflict in recreational use by six different user groups in the Black Forest Nature Park in southwest Germany. Results from hikers and mountain bikers are analyzed and compared in depth. The results elucidate some of the general cultural differences between “nature-oriented” recreationists (hikers), and “activity-oriented” recreationists (mountain bikers), and how each perceives infrastructural and social conflicts.

Mason, Peter, & Sarah Leberman. 2000. Local Planning for Recreation and Tourism: A Case Study of Mountain Biking from New Zealand's Manawatu Region. Journal of Sustainable Tourism, vol.6 no.2, pp.97-115.

User surveys and use monitoring are employed to assist in the identification of MTB rider preference (terrain, duration of trip, etc.) and potential user conflict. An iterative approach to planning mountain bike use in the Manawatu region of New Zealand is favourably compared to the reactive, *ad hoc* approach that has been used more commonly in the past.

Mosedale, Jan. 2003. Planning for Appropriate Recreation Activities in Mountain Environments: Mountain Biking in the Canadian Rocky Mountains. York University, Faculty of Environmental Studies Outstanding Graduate Student Paper Series, vol.7 no.5. 114pp.

A review of the literature on ecological and social impacts associated with mountain biking. The author assesses the current state of MTB activity in multiple areas (under different jurisdiction/management) along the Rocky Mountains from Edson Alberta south to Fernie BC. Best management practices are proposed and discussed.

Naber, Michael David. 2008. Integrating Trail Condition Assessment with Recreational Demand Modeling of Mountain Bikers in the Research Triangle, North Carolina. PhD Thesis. North Carolina State University. 119pp.

Solidly in the gray area between sociological and ecological aspects of recreation study, the author models demand for mountain biking (recreation demand) on six trails in North Carolina, using variables related to trail challenge (level of difficulty), degree of environmental degradation (erosion, exposed roots, trail surface material, landform, etc. - variables mostly related to soils and

vegetation), and extent of development of associated facilities/infrastructure. Condition of trails was measured systematically. The findings of this study suggest that mountain bikers exhibit a strong preference for trails that are technically challenging, that have well-developed facilities, and that have a minimal amount of environmental damage.

Symmonds, Mathew C., William E. Hammitt, & Virgil L, Quisinberry. Managing Recreational Trail Environments for Mountain Bike User Preferences. Environmental Management, vol.25 no.5, pp.549-564.

An online survey was conducted in order to determine preferences of mountain bikers related to environmental and landscape characteristics of trails (e.g. soil erosion and management thereof). The survey was administered globally, with most responses coming from the US, UK, Australia and New Zealand. Water bars were found to be a preferred erosion control technique, though many respondents demonstrated a preference for heavily eroded (rooty, rocky, gullied) terrain.

Modeling Tools for Recreation Ecology

Bennett, Victoria J., Matthew Beard, Patrick A. Zollner, Esteban Fernandez-Juricic, Lynne Westphal, & Cherie LeBlanc. 2008. Understanding wildlife responses to human disturbance through simulation modeling: A management tool. Ecological Complexity (2008), doi:10.1016/j.ecocom.2008.08.002.

An illustration of the use of a spatially explicit modeling tool called SODA (Simulation of Disturbance Activities), using two case studies. SODA focuses on modeling the ecological impacts of disturbance (recreational use) related to wildlife ecology and habitat. Parameterization of the model allows for consideration of different types of recreation. Some cited references may be valuable for better understanding of recreation ecology.

Cole, David N., & Terry C. Daniel. 2003. The Science of Visitor Management in Parks and Protected Areas: From Verbal Reports to Simulation Models. Journal for Nature Conservation, vol.11, pp.269-277.

A study on the evolving science of monitoring type and intensity of human recreational use in wilderness areas. The authors argue that traditional surveying methods do not provide an accurate assessment of human recreation patterns, and that a more robust and defensible approach is required. To this end they propose the use of travel simulation modeling approaches (e.g. Extend).

Itami, Robert, Rob Raulings, Glen MacLaren, Kathleen Hirst, Randy Gimblett, Dino Zanon, & Peter Chladek. 2003. RBSim 2: Simulating Complex Interactions Between Human Movement and the Outdoor Recreation Environment. Journal for Nature Conservation, vol.11, pp.278-286.

Introduction to a human recreational behaviour simulation modeling application, RBSim 2. The application allows for the spatially explicit assessment of changes to use, behaviour, and environmental impacts that could be expected to result from hypothetical changes to trails (or other linear features) and associated infrastructure.

General Recreation Ecology – Not Mountain-Bike-Specific

Bath, Alistair J., & Jody W. Enck. 2003. Wildlife-Human Interactions in National Parks in Canada and the USA. Social Science Research Review, vol.4 no.1, 32pp.

A literature review that identifies the principle concerns and issues related to human-wildlife interaction within national parks. Though a good general overview of the issues, there is no specific mention of mountain biking, or comparison of the nature of human-wildlife conflict for cyclists as compared to other uses.

Blumstein, Daniel T., Esteban Fernandez-Juricic, Patrick A. Zollner, & Susan C. Garity. 2005. Inter-specific Variation in Avian Response to Human Disturbance. Journal of Applied Ecology, vol.42, pp.943-953.

Using recorded data published between 1980 and 2003, the authors modeled behaviour of 150 avian species in response to human disturbance. The model suggests that detection distance is a key factor explaining inter-specific variation in response to human disturbance, and that in general, larger birds detect human presence at greater distance than smaller birds. Certain fitness-related factors (e.g. quantity of food consumed) were found to be sensitive to detection distance, suggesting the need for consideration of impacts on avian species when managing human activity within their habitat.

Crealock, Anne G. 2002. The Role of Trails and Trail-Users in the Spread of Non-Native Plants. MSc Thesis, San Jose State University.

Thesis that examines the role of human use trails as both habitat and vectors for spread of invasive plant species. Studies are conducted in field and simulated situations that compare different types of trail use, and conclude that non-native invasion is facilitated by all types of recreation, and that different invasive species respond differently to different types/levels of use.

Hadwen, Wade L., Wendy Hill, & Catherine M. Pickering. 2007. Icons Under Threat: Why Monitoring Visitors and Their Ecological Impacts in Protected Areas Matters. Ecological Management & Restoration, vol.8 no.3, pp.177-181.

The authors point to the threats of overuse at “icon sites” due to increased levels of human recreational activity. They suggest current methods of collection and reporting of visitor data are inadequate to answer important questions related to ecological impact and carrying capacity, and make the case for more proactive, targeted visitor impact monitoring.

Hebblewhite, Mark, & Evelyn Merrill. 2008. Modelling Wildlife-Human Relationships for Social Species with Mixed-Effects Resource Selection Models. Journal of Applied Ecology, vol.45, pp.834-844

A resource selection function (RSF) model is applied to demonstrate that behaviour of wolves (*Canis lupus*) changes with proximity to human activity, and that different packs of wolves exhibit different behaviour. Specifically, the authors report that in areas of elevated human activity, wolves selected areas closer to humans (though they avoided humans during daylight).

Knight, Richard L., & Kevin G. Gutzwiller, Eds. 1995. Wildlife and Recreationists: Coexistence Through Management and Research. Island Press. 372pp.

A book dedicated to describing the current (1995) state of knowledge in the field of wildlife recreation ecology. Sections on general theory, specific case studies and examples, and management implications are included. Very little specific reference to mountain biking and its impacts on wildlife.

Liddle, Michael. 1997. Recreation Ecology: The Ecological Impact of Outdoor Recreation and Ecotourism. Chapman & Hall. 639pp.

The standard recreation ecology textbook, and a good overview of the theory and underlying principles of recreation ecology.

Marion, Jeffrey L. 1998. Recreation Ecology Research Findings: Implications for Wilderness and Park Managers. USGS Patuxent Wildlife Research Center. 6pp.

A brief summary of recreation ecology, including recommended further reading. Focus of section on environmental impacts is on soils and vegetation.

Sun, D., & D. Walsh. 1998. Review of Studies on Environmental Impacts of Recreation and Tourism in Australia. Journal of Environmental Management, vol.53, pp.323-338.

A review of literature related to the ecological impacts of Australian recreation and tourism, with a focus on vegetation and soils. Some inter-use comparison is attempted, but more informative cross-use assessments can be found in other literature reviews cited herein.

Tempel, Douglas, Vita Wright, Janet Neilson, & Tammy Mildenstein. 2008. Linking Wilderness Research and Management – vol.5. Understanding and Managing Backcountry Recreation Impacts on Terrestrial Wildlife – An Annotated Reading List. USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO. 70pp.

An extensive annotated reading list of impacts of backcountry recreation on wildlife behavior and habitat. Subsections include general concepts, specific examples, management policies and practices, and other resources. No specific mention or citation of research related to mountain biking.

Wagar, Alan. 1964. The Carrying Capacity of Wild Lands for Recreation. Forest Science, Monograph 7. Society of American Foresters. 31pp.

Mostly of archival interest, Wagar attempts to lay some foundation for the future consideration of ecological carrying capacity when managing for recreational use of public wilderness. Even in 1964 it was clear that both ecological and social costs and benefits need to be considered by land managers.