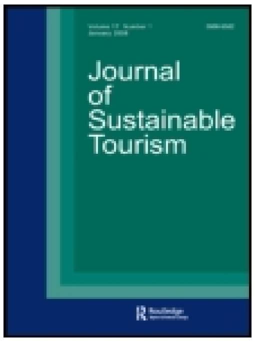

Journal of Sustainable Tourism

ISSN: 0966-9582 (Print) 1747-7646 (Online) Journal homepage: https://www.tandfonline.com/loi/rsus20

Sustainable Mountain Biking: A Case Study from the Southwest of Western Australia

Ute Goeft & Jackie Alder

Sustainable Mountain Biking: A Case Study from the Southwest of Western Australia

Ute Goeft
Centre for Ecosystem Management, Edith Cowan University, Joondalup, Western Australia

Jackie Alder
Centre for Ecosystem Management, Edith Cowan University, Joondalup, Western Australia

The environmental impacts of mountain biking and rider preferences in Southwest Western Australia were analysed to determine appropriate trail design and to ensure that this popular nature-based activity has minimal environmental impact while meeting rider requirements. Environmental impacts such as soil erosion and compaction, trail widening and changes in vegetation cover on a recreational trail and racing track were monitored for 12 months to determine the short- and long-term effects of riding during winter (rainy) and summer (dry) seasons. Rider preferences were determined through a survey of mountain bike riders in the region. The study found that trail erosion, soil compaction, trail widening and vegetation damage can occur but they can be avoided or minimised with appropriate trail siting, design and management. The study also found that rider preferences for downhills, steep slopes, curves and jumps along with water stations and trail markings need to be included in the siting and design of the trails. When multiple-use trails are considered, mountain bikers are willing to share the trail with other users except motorised vehicles.

Introduction

Tourism is increasing globally with ecotourism and nature-based tourism making up 20% of total international travel (World Tourism Organisation, 1998). In 1995 there were more than 600 ecotourism operators and 2000 adventure outdoor businesses in Australia (Cotterill, 1995 cited in McKercher, 1998). In 1997 Western Australian nature based-tourism was projected to increase annually by 25–30% (Western Australian Tourism Commission, 1997). Concerns, however, over the environmental impacts of many tourism activities and the ability of the industry and the environment to meet the demand have also been raised (Mason & Moore, 1998; World Tourism Organisation, 1998). Specific activities such as scuba diving (Hawkins & Roberts, 1993), camping (Sun & Walsh, 1998) and recreational fishing (Kirkegaard & Gartside, 1998) have the potential to degrade the environment. Mountain bike riding is another activity where concerns over environmental impacts (Chavez, 1993), user conflicts (Cessford, 1995a; Horn *et al.*, 1994; Moore & Barthlow, 1997) and user demands for expanded trail networks (Brindal & Department of Conservation and Land Management [CALM], 1995) have been expressed.

0966-9582/01/03 0193-19 $16.00/0

The popularity of mountain bike riding, especially in natural settings, has increased steadily since its inception in the 1970s; 90% of bikes sold in the United States in 1993 were mountain bikes (Bjorkman, 1996). In Wellington, New Zealand, mountain bike riding is the second most popular recreational activity (Wellington Regional Council, 1996). Canada, New Zealand and the United States are among several international tourist destinations offering mountain bike riding as a thrill-seeking nature-based activity through guided or unguided tours. The increase in the number of trails and number of riders, however, has also heightened concerns for the environmental impacts of the sport (Chavez, 1993) and user conflicts (Cessford, 1995a). Mountain bike riding appears to be a growing activity in Australia: no statistics are available, however, for either participation levels or sales of mountain bikes in Australia.

Few studies have examined the environmental impacts, the user conflicts and user demands of mountain bike riding in natural settings together. There is also no known study that has integrated these issues to manage the activity better through improved trail locations, trail design and management recommendations. This paper reviews the current studies on these issues and management practices for mountain-bike trail design, before describing a study of the environmental impacts of mountain biking at two sites and user demands of bike trails in southwest Western Australia. The study found soil erosion, soil compaction, trail widening and vegetation damage to be potential impacts of mountain bike riding and that user preferences for such features as downhills, steep slopes, curves and jumps could contribute to these impacts. The subsequent discussion, however, illustrates how environmental requirements and user demands can be integrated into the design of sustainable trails in the southwest of Western Australia.

Environmental Impacts of Mountain Bike Riding

Mountain bike riding, by its very nature, is an activity mainly pursued on trails and similar features such as old logging roads and fire tracks in parks, reserves and other natural settings. Most physical impacts, therefore, relate to changes on the trails and adjacent areas.

Environmental impacts on trails and surrounding areas are primarily soil and vegetation related (Sun & Walsh, 1998). Soil compaction, erosion, trail widening and vegetation disturbance are commonly cited direct impacts, but they vary in severity with location, soil type, rainfall and use (Sun & Walsh, 1998). The establishment of a track in a natural setting alters the environment and, therefore, its very existence can be a source of impacts, especially for soil disturbance, erosion and vegetation loss (Sun & Walsh, 1998). Once a trail is formed any further use only adds to these effects. Seney and Wilson (no date) found that trail users cause approximately 35% of all erosion impacts on trails. The other two-thirds are attributable to a complex interaction of natural influences, such as rainfall and water runoff, terrain and soil texture and vegetation cover.

Little information with respect to mountain-bike-specific impacts is available for Australian conditions. Trail impact studies to date in Montana (Wilson & Seney, 1994), Wisconsin (Bjorkman, 1996) and Germany (Wöhrstein, 1998) were conducted on trails used for mountain biking as well as walking, horse riding and motorcycling. These studies examined erosion, soil loss, trail width and vegetation cover. Some findings from these studies highlight where mountain bike impacts differ from other trail uses.

In their field experiment, comparing the physical impacts of mountain biking, hiking, horse riding and motorcycling in the mountains of Montana (United States), Wilson and Seney (1994) found that mountain biking impacts, such as soil compaction and sediment yield, were less than those of walking. Although mountain bikes would be expected to cause less impact than motorcycles, Cessford (1995a) conceded that mountain bikers can potentially damage trails while travelling downhill if they skid and employ poor braking techniques, especially in casual racing or training situations. These practices loosen the track surface, move material down the slope and create ruts, which channel water flow.

Wöhrstein (1998) examined soil compaction during the 1998 World Championship Cross Country race in Germany where 870 participants rode the course a total of 6000 times and were cheered on by 80,000 spectators. He found more compaction to a shallower depth for mountain bikes compared to spectators where compaction was less but deeper. A field experiment involving 50 passes, by a mountain bike and a walker respectively, resulted in comparable levels of compaction. In all cases compaction levels in the first 3.5cm had reverted to pre-existing levels within 19 months. This suggests that in the southwest of Western Australia, where trails can be used for these three activities (recreational mountain biking, mountain bike racing and walking), soil compaction should not vary significantly between the users.

Trails will often have a compacted surface depending on the soil texture, the moisture content of the soil and the amount of use. The denser a soil is packed, the fewer pores are available and the longer it will take for water to infiltrate. This will increase runoff especially on slopes (Liddle, 1997; Lal & Elliot, 1994). The velocity of runoff is dependent on the incline of a slope whereas the length of a slope influences the amount of runoff, hence long steep slopes generate the most erosion (Marsh, 1991).

Soil texture is one of the most important factors influencing the erodibility of a trail surface. Fine sands and silts are the most easily eroded soils (Liddle, 1997; Bjorkman, 1996; Marsh, 1991; Cole, 1983) and erodibility is reduced with increasing clay content (Bjorkman, 1996). Coarser soils and sands, however, need considerable force to be moved (Wöhrstein, 1998; Lal & Elliot, 1994; Marsh, 1991). Rougher soil surfaces, for example on soils with a mix of grain sizes including pebbles or rocks, reduce water velocity thereby decreasing its capacity to transport soil and its erosion potential (Wöhrstein, 1998; Liddle, 1997; Lal & Elliot, 1994).

The type of user and their location on the trail (uphill or downhill) influences soil compaction. A mountain biker with high-profile tyres will exert maximum pressure (14 kg cm^{-2}) on the trail when riding uphill, whereas walkers exert maximum pressure (56 kg cm^{-2}) descending a hill (Wöhrstein, 1998). On level ground, however, walkers reach comparable and often higher pressures than mountain bike riders.

In the German study described earlier, Wöhrstein (1998) found little erosion attributable to mountain bike racing and erosion was evident only for trails subjected to frequent racing and confined to areas subjected to intense mechanical wear or stress. Wöhrstein (1998) also noted that linear tracks were formed by mountain bike riding on trails with a viscous surface. However, the tracks were often deformed by other users (e.g. walkers) and only remained for short periods of time making it difficult to assess the extent of the impact from racing. The greatest erosion potential was seen in saturated soils on steep slopes and high water runoff conditions.

In Wisconsin, Bjorkman (1996) demonstrated that in areas of high runoff on a bare inclined surface any kind of use accelerated soil loss. The soil loss from a bare trail was 100 times greater than soil loss from a trail where geotextile matting, a synthetic material that allows water to flow through but reduces soil movement, was used to reduce water runoff. Cessford (1995c) found that mountain biking was associated with soil erosion, track widening and informal and parallel tracks. Some of these impacts were due to poor riding technique (e.g. skidding). Therefore, trail erosion can be dependent on site and soil conditions and rider behaviour (Chavez *et al.*, 1993). In Deschutes National Forest (USA) mountain bike riders went around log-style water bars creating additional erosion and trail widening problems (Hain, 1986; cited in Chavez *et al.*, 1993). Indirect impacts can also occur especially where trail design is inappropriate.

Trail erosion can occur in dry conditions. Wilson and Seney (1994) found that the sediment yield of the trails they examined was mainly due to soil loosening. This was reduced when a trail was wet due to increased soil cohesiveness (Deluca *et al.*, 1998; Parker *et al.*, 1995). Dislodgement of soil will happen through normal trail use and can be exacerbated through hard braking and skidding (Cessford, 1995c).

In the southwest of Western Australia trails are most vulnerable to soil erosion in wet conditions and therefore measures to reduce the impact of rain on trails must be considered in trail siting. Vegetation cover on and beside the trail can reduce soil erosion (Wöhrstein, 1998; Marsh, 1991). Litter cover reduces raindrop velocity as well as water runoff velocity thereby reducing the erosion potential. Vegetation further reduces erosion since plant roots bind the soil (Marsh, 1991). A forest canopy can reduce surface runoff to 10% of the incoming rain (Ammer, 1983, cited in Wöhrstein, 1998).

Social Concerns

Multiple-use trails are characterised by conflict between users and because mountain bikes often share trails with walkers, horse riders, motorbikes and four wheel drive vehicles a range of conflicts and concerns are evident (Moore, 1994). The primary social concerns are safety, trail damage, lack of environmental awareness and the inappropriate use of technology in natural settings (Cessford, 1995a). This has led to debate over the most appropriate use of trails (Horn *et al.*, 1994). These conflicts, if not resolved, could ultimately lead to lost trail opportunities (Moore & Barthlow, 1997) due to insufficient cooperation among users.

Horn *et al.* (1994) noted that most conflict between mountain bikers and walkers in New Zealand occurred close to urban areas and that 65% of walkers who participated in the study disliked mountain bikers especially recreational riders. Carrothers *et al.* (1998) found that the levels of conflict that hikers perceived with mountain bikers were higher than those that bikers perceived with hikers. In Wisconsin (USA) the sources of conflict between hikers and mountain bikers were trail displacement, right of way and speed, changed trail experience and environmental impacts (Bjorkman, 1996). Similar conflicts can be expected in the southwest of Western Australia, and addressing these conflicts which are varied, asymmetric and complex will require information on the scope and nature of the conflict between trail users.

Petit and Pondes (1987) and Ford (1989) (both cited in Chavez *et al.*, 1993) examined the issues related to safety and concluded that the risk of accidents was small. Few studies to date have recorded accidents involving walkers and mountain bike riders (Chavez *et al.*, 1993), and the Wellington Regional Council (1996) stated that the actual records of injuries to walkers did not seem to match their perceptions of such. Chavez (1996b) found that high speeds and the quietness of mountain bikers contributed to the safety issue in US forests. A source of conflict was rider behaviour; mountain bikers often approached other users too fast for the trail conditions and were not prepared to slow down (Horn *et al.*, 1994; Watson *et al.*, 1991; Widmer, 1997). In the United Kingdom, however, few walkers perceived mountain bikes as hazardous or a source of dissatisfaction (Jacoby, 1990).

The perceptions by other trail users that mountain bikes cause environmental damage is noted in a number of studies (Cessford, 1995c; Horn *et al.*, 1994). This perception can also be found amongst managers of public lands in the United States (Chavez *et al.*, 1993; Chavez, 1996a,b) although managers noted that it was hard to distinguish between damage by different users and by increasing use.

Traditional users in Los Padres National Forest (USA) did not like mountain bike riders because they were so new (Petit & Pondes, 1987, cited in Chavez *et al.*, 1993). A Wisconsin study observed that over 70% of riders did not announce themselves when passing walkers, and this may explain why walkers disliked riders when interrupted on the trail and had their wilderness experience diminished (Bjorkman, 1996). Walkers in a New Zealand study also expressed similar sentiments (Horn *et al.*, 1994) regarding reduced wilderness experiences when mountain bike riders were encountered.

Rider Preferences

Specific studies of rider preferences have been limited to one New Zealand study (Cessford, 1995a) and one study in the United States (Hollenhorst *et al.*, 1995). Other studies in the United Kingdom (Ruff & Mellors, 1993); the United States of America (Watson *et al.*, 1991; Chavez, 1993; Blahna *et al.*, 1994; Blahna *et al.*, (no date); Hollenhorst *et al.*, 1995) and Germany (Wöhrstein, 1998) examined specific rider characteristics, such as behaviour, perceptions and demographics that assist in describing rider preferences. Two common themes emerge from this mix of studies. Most riders prefer natural settings to ride in and riders prefer trails with a variety of features such as slopes and curves. All researchers also found that males around the age of 30 years dominated mountain biking, although participants were slightly younger in New Zealand and Germany compared with the US and the UK. These finding are consistent with mountain biking being regarded as a form of adventure recreation (Priest & Dixon, 1990) where participants look for a certain element of risk, excitement and peak experiences (Ewert, 1989; Hollenhorst *et al.*, 1995).

The Western Australia Case Study

Background

The Western Australian Government published a 'Nature Based Tourism Strategy' (Western Australian Tourism Commission, 1997) in response to the increasing popularity of nature-based activities such as hiking, camping and bicycling in natural settings. Bicycle use in Western Australia has increased in recent years (CALM, 1997, 1999), due, in part, to a growing interest in mountain biking as a sport and recreational activity. Trails currently used for recreational mountain biking in Western Australia include vehicle tracks, walking trails, equestrian tracks and some mountain bike specific trails (CALM, 1997). Some trails that have been approved for mountain bike use are not designed specifically for use by mountain bikes and other trails are used illegally by mountain bikers (E. MacGregor, Trailswest,[1] pers. comm. 1999). These trails may be susceptible to specific environmental impacts caused by mountain bikes and subject to user conflicts associated with mountain biking.

Trailswest in association with the Western Australian Mountain Bike Association (WAMBA) and the Department of Conservation and Land Management plan to increase the number of trails for specific use by mountain bikes as well as multiple use ones to accommodate walking, horse riding and mountain biking (E. MacGregor, Trailswest, pers. comm. 1999). In addition, existing and future mountain bike loops are planned to connect and form a long-distance trail (M. Ahrens, WAMBA, pers. comm. 1998). Consequently, there is a need for reliable information on environmental management requirements and user preferences in the development, operation and management of mountain bike facilities by the managers of forests and trails in Western Australia.

The current approach to trail design in Western Australia is founded on landscape architecture and design principles that are adapted as needed. If there is no other option but for a trail to traverse areas susceptible to soil erosion or excessive compaction, or if extreme degradation is occurring, hardening of the trail surface, for instance by using boardwalks, gravel or bitumen is recommended (Mike Bodsworth, pers. comm. 1999). The *Tasmanian Walk Track Manual* (Department of Lands, Parks and Wildlife, 1987) is used for basic specifications of trails and a basic trail classification system is applied. Neither approach deals with the specific environmental impacts of mountain biking nor rider demands to ensure that sustainable trails are developed. Clearly, if trails are to be expanded and sustainable, environmental requirements and user demands must be integrated into trail design.

Methodology

Two studies were initiated in the southwest of Western Australia to investigate (1) the physical impacts of mountain biking under recreational use and cross-country racing conditions; and (2) rider needs and perceptions.

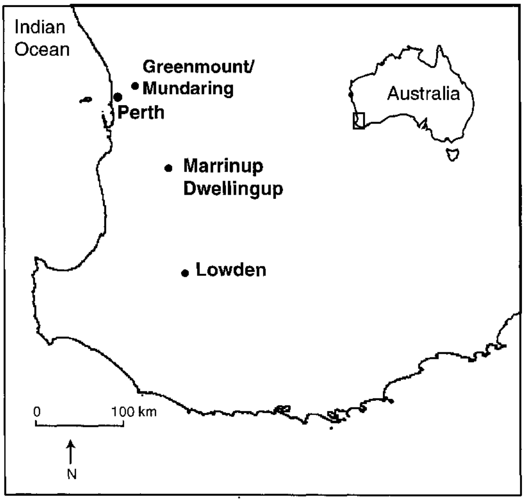

Figure 1 Location of study areas and preferred rider destinations (scale in km)

Physical impacts

The study sites were a recreation trail located at Marrinup and a racing trail located at Lowden (Figure 1). The recreation trail (10.5km long) was opened in 1997 and is used occasionally for racing. It traverses a mixed regrowth forest in a rehabilitated mine site and original forest, and follows stretches of single track with loop backs composed of fire tracks and a service track. The racing trail (3.7km long) is on private property and the owner controls access. It traverses forest with an understorey. Sections of the trail were up to five years old during the study while other sections were opened at the commencement of the study. The different ages of the trail provided an opportunity to investigate the initial, as well as ongoing and accumulative, impacts of racing. Not all parts of the track necessarily received the same use and it was not possible to measure use levels in each section of track.

On each trail, three replicated transects representing combinations of uphill, downhill and flat sections with curved and straight sections were selected. At each transect soil compaction, soil erosion measured as the percentage change in trail profiles, trail width and vegetation cover were examined for one year. Sun and Walsh (1998) identified soil compaction, erosion, trail width and vegetation cover changes as significant environmental impacts in natural areas subjected to tourist and recreational use. Therefore, these features, along with soil characteristics, aspect and incline, were studied as part of the physical impact study. The recreation trail was sampled five times in summer (September 1998 to February 1999) and twice in winter (May 1999 to September 1999), while the racing trail was sampled six times in summer and twice in winter.

Soil erosion was measured by examining the percentage change in the cross sectional area of the trail profile between the start of the study and the subsequent sampling times (Coleman, 1977; Cole, 1983). Soil compaction (kg cm^{-2}) was measured using a hand held penetrometer (Humboldt) at 5 cm intervals across the trail. Trail width was determined by measuring the maximum width of ground used by mountain bike riders as evidenced by tyre marks. Vegetation damage was examined by observing changes to plants within 2m of either side of the trail. Soil samples were taken immediately next to the trail to determine various soil parameters.

Erosion, soil compaction and trail width were analysed by analysis of variance (ANOVA) and analysis of covariance (ANOCOVA) using SPSS version 7.5 for Windows. The data were analysed as a repeated measures general factorial ANOVA crossing features with incline and age. Levene's test of equality of error variances (SPSS version 7.5) was performed initially and indicated that errors for all three variables were not homogeneous. Various soil parameters (depth of O2 and A horizon,[2] percentage fragments of horizon A and B, fragment size of horizon A and B) as well as slope and aspect were transformed as appropriate (arcsine for percentage fragments) and used as covariates in the ANOCOVA analysis.

Rider characteristics

A survey of mountain bike riders in the southwest of Western Australia was conducted using a short four-page questionnaire designed to generate information on the following four areas of user management:

- how and why mountain bike riders use trails;
- the preferences of mountain bikers in regard to trail features, settings and trail locations;
- the perceptions of mountain bikers in regard to impacts of the sport on the environment and in respect to aspects of management; and
- rider demographics.

The questionnaire was composed of a mix of open, closed and Likert scale questions. Nine hundred and eighty questionnaires were distributed through mailing lists, bike retailers, CALM offices and personal contact with riders on the trail in the southwest of Western Australia and the Perth area.

The reasons riders participate in mountain bike riding were explored along with the frequency and intensity (average distance travelled) of participation. The extent to which riders like to encounter other trail and track users was investigated. Rider preferences for various trail features (surface, slopes, length of uphill and downhill, curves, facilities and information) were studied. In addition, the settings (native bush, plantation forest, farmland, suburbs, sealed or unsealed roads, wide trails or single track) riders preferred were explored. Rider participation in long-distance touring and the demand for touring trails were also examined. Rider perceptions of a range of statements on mountain bike management and environmental awareness were recorded.

The data were analysed using SPSS for non-parametric statistics appropriate to the style of question. Percentages were used for closed questions, means and modes for Likert scales and counts for the open questions. In some cases, responses were tested using cross tabulations with chi-squared tests (SPSS 7.5 for Windows) to test for differences between recreational and racing riders.

Results

Physical impacts

Erosion (percentage change), soil compaction and trail width data were variable at both sites. Some of the erosion variability can be attributed to the limited

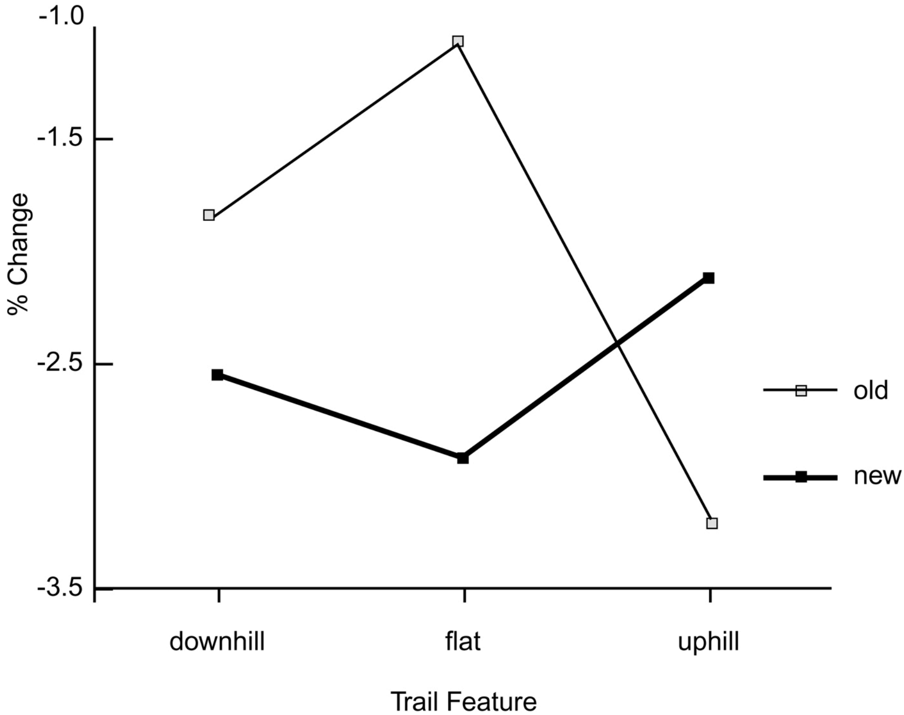

Figure 2 Erosion (% change in micro relief profile) at Lowden

sensitivity of the measuring device and the intrusion of vegetation. Soil compaction variability was higher at Lowden especially between new and old sections of the trail. The sources of variability for trail width were not identified. Nevertheless, ANOVA were undertaken since it is relatively robust to heterogeneous variances. ANOVA using appropriate transformations for erosion and soil compaction were explored, however, the analysis with transformed data did not change the outcomes of the original analysis. ANOCOVA were also carried out and the only significant covariates were the soil depth of the A horizon at Marrinup when erosion was analysed.

The study indicated that slope, time and age are significant erosion factors for trails in the study sites. At Lowden the slope–age interaction (Figure 2) was significant ($p = 0.035$). At Marrinup there was a significant ($p = 0.046$) interaction between time, feature and slope (Figure 3). In particular, downhill slopes and curves were the most susceptible to the erosion impacts of mountain bike riding. There was a significant relationship between the depth of the A horizon and soil erosion at Marrinup, however, when the data were adjusted for this relationship the interaction remained.

At some of the Lowden sites soil compaction changed over time (Figure 4), there was a peak in soil compaction at time 3 and then a loosening of the soil at time 6 (after the summer race) and subsequent compaction. At Marrinup, overall the data were less variable (Table 1) and the sites were more compacted than at Lowden with some of the sites showing consistent results over the time of the study.

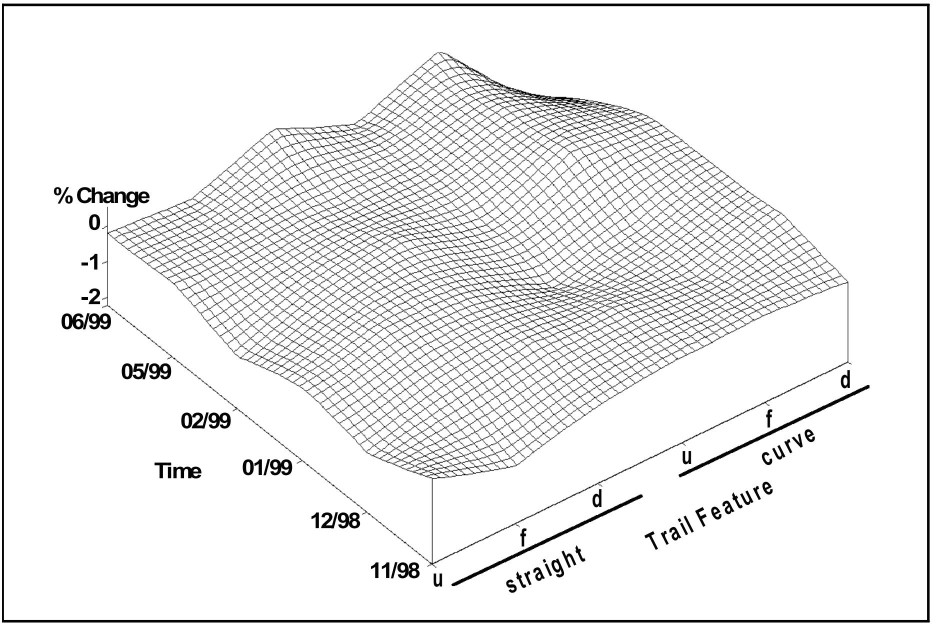

Figure 3 Erosion (% change in micro relief profile) at Marrinup between first sample (10/98) and subsequent samples (u = uphill; f = flat; d = downhill)

Soil compaction at Lowden was also the result of a significant ($p = 0.024$) interaction between slope, time and age (Figure 4). In addition to this three-way interaction, there was a significant ($p = 0.033$) lower-order interaction of time and slope. Overall, the 'old' features were more compacted than the 'new' features. At Marrinup where soil compaction was less variable, time (Table 1) was the only significant factor ($p = 0.000$).

Trail width changed significantly ($p < 0.05$) over time at both study sites (Figure 5) and there were no further effects or interactions. The width of the trail at Lowden increased initially and then retreated to its minimum at the end of

Table 1 Mean soil compaction and least significant difference ($p < 0.05$) at Marrinup after each sampling time

Date	Sampling event	Mean	2	3	4	5	6	7
10/98	(1)	2.82	*	*	*	*	*	*
11/98	(2)	2.68				*	*	*
12/98	(3)	2.60					*	
1/99	(4)	2.51						
2/99	(5)	2.38						
5/99	(6)	2.47						
6/99	(7)	2.33						

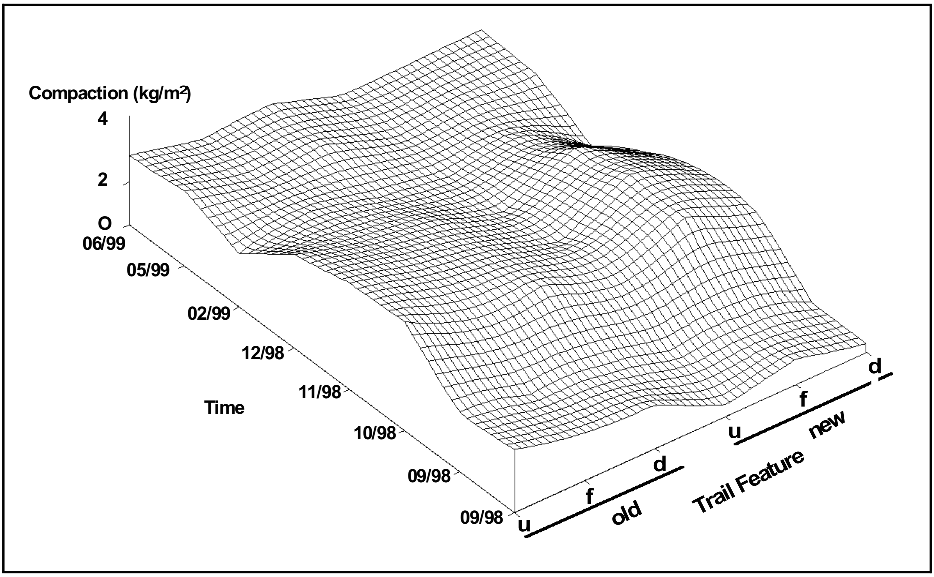

Figure 4 Soil compaction (kg/cm^2) at Lowden over time (u = uphill; f = flat; d = downhill

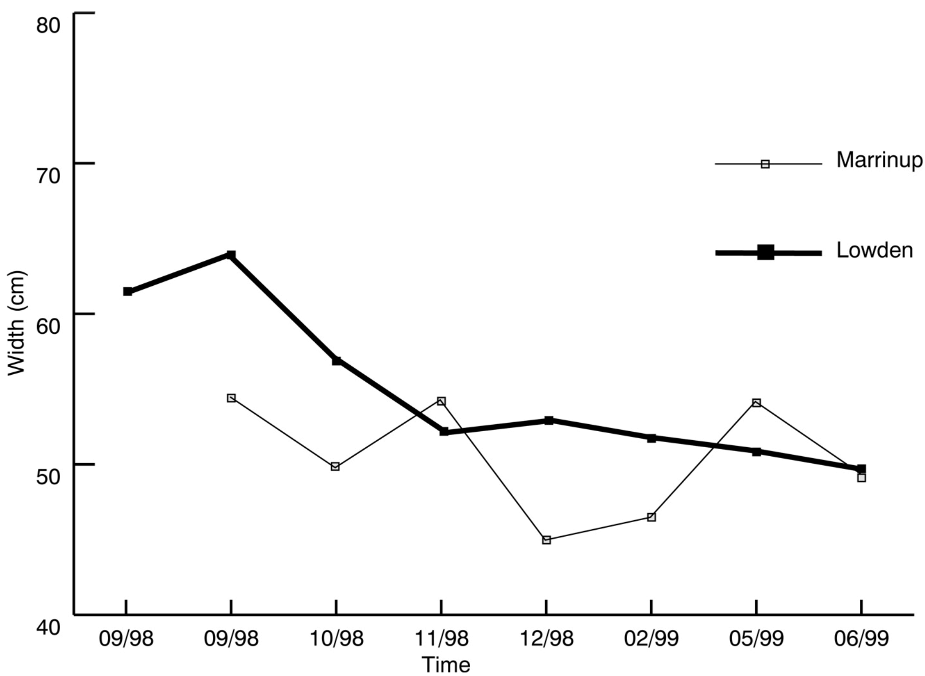

Figure 5 Average trail width (cm) at Lowden and Marrinup

summer. This trend, however, was not evident at Marrinup, where trail width varied throughout without increasing in overall width.

Visual observation recorded minimal vegetation damage to areas within 2m of the trail. When vegetation was disturbed after the summer race it was minor or temporary and not noticeable on the next sampling occasion.

Rider preferences

The results of the rider preferences and perceptions are detailed in Goeft and Alder (2000). This section presents a synthesis of the results of the study that are relevant to sustainable trail design.

One hundred and eighty three questionnaires were returned resulting in a response rate of 19%. The response rate was low due to the difficulties in motivating riders to return survey forms distributed through retail outlets. Nevertheless a sample size of 183 was considered large enough to investigate rider preferences. Survey respondents were primarily male, 15 to 39 years of age, and residing in the Perth Metropolitan area in Western Australia. The majority of respondents were mountain bike club members and, therefore, the potential to introduce some bias existed. The analysis of club members indicated that although they ride for recreation, many more club members also race compared to non-member respondents. Comparisons between the recreation-only riders and recreation/racers, however, detected only a few significantly different results in the answers to eight questions and these are discussed later.

The survey indicated that respondents ride mountain bikes because it is fun, healthy, challenging and a social activity. Racing was listed as an important reason and this may reflect the interest of the majority of respondents who were club members. Mountain bikes were also seen as a good means of transport and a way to experience nature and to relax by half of the respondents.

The rides undertaken by most respondents (78%) were longer than 10km and many respondents (74%) rode at least two to three times per week. Some respondents indicated that they rode short distances to work and school and longer distances for recreation or racing rides. Respondents identified the following areas as popular mountain-bike-riding destinations: Dwellingup, Mundaring and Greenmount; all are located in natural settings (Figure 1).

The most preferred trail features, with a mode of 1 (essential on the scale), were downhills (long, medium and short), long curves, tight curves, steep slopes, jumps, rocks, logs and short uphill sections. The most preferred trail facilities were drinking water and route markers. The least preferred trail features (mode = 3 (okay)) were smooth surfaces, loose sand or gravel, muddy areas and overhanging branches. The modes for the remaining trail facilities were between 1 and 3.

The most preferred settings, where the mode equalled 1(essential), were single tracks and native bush or forest. Sealed roads and built-up areas/suburbs were the least preferred settings (modes of 3 (okay) and 4 (try to avoid) respectively). Respondents' reactions to encounters with wildlife (mode = 1.6) and other cyclists (mode = 1.7) ranged from loving it (1) to considering it quite good (2) whereas they did not like (4) encounters with cars (mode = 3.8) and motorcycles (mode = 3.78).

Less than half of the respondents indicated that they had undertaken overnight or longer tours, but many of these respondents (60%) indicated that they wanted to participate in such tours. In fact, 12 respondents specified in the additional comments section at the end of the survey that they wanted long touring trails . These 12 comments are significant since these respondents were willing to take the time to specifically comment on the need for such trails.

Respondents perceived that there were not enough mountain bike trails and that mountain bikes should be allowed on all trails. The overwhelming majority of respondents did not consider mountain bike riding damaging to trails and most respondents thought the perception of damage was overrated. Many riders did associate soil type with trail damage and thought that what damage there was could be controlled with good riding technique, education and trail design. Respondents' perceptions of other environmental impacts of mountain bike riding, such as impacts of racing *versus* touring, trail damage in downhill curves and the spread of dieback disease by mountain bikes were varied. Riders were also divided on the issue of whether riding the same trail repeatedly is enjoyable.

When the interactions of recreational riders and recreational/racing riders with trail features were investigated, significant relationships were found. Riders who recreationally ride and race regarded downhills (long, medium and short length) and long curves as essential, whereas recreational riders only rated these features as good. Tight curves were essential for racers and neutral for recreational riders. In contrast, recreational riders regarded drinking water and route markers as essential or good yet racers considered them good to neutral. Riders who race regarded jumps as essential, while recreational riders were neutral to negative towards them.

Single tracks were essential for recreational riders who race and riders also considered plantation forests to be desirable settings. Recreational riders, however, did not have a preference for single trails over other trails and were generally positive towards plantations. In contrast, racers avoided gravel roads and recreational riders had no clear preference for this road surface. Both groups, however, either avoided or were neutral to sealed roads.

Implications for Sustainable Trails

The sustainability of mountain bike riding in natural settings relies on incorporating the environmental sensitivity of the area under consideration and measures to reduce the impact of riders into the design of trails, while meeting rider preferences. Cessford (1995a) pointed out that trail design, in regard to surroundings, incline and length of a trail, as well as difficulty and variation of a course plays an integral part in satisfying these user expectations. Therefore, appropriate design and management of mountain bike trails requires information on how mountain bike riders actually use trails and what they expect in terms of experiences and settings (Cessford, 1995c).

Previous studies (Wöhrstein, 1998; Bjorkman, 1996; Wilson & Seney, 1994), as well as this study, have shown that physical impacts – soil compaction, erosion and trail widening – can result from mountain bike riding, but soil compaction and erosion are confined to the trail itself with minimal change to adjacent areas. This study also found that trail widening was not significant, but changes in trail width reflected the nature and type of use. Trails used for racing were widened after a race and this widening was more pronounced in moist soil conditions than in dry soils.

These studies together with this one also noted that the extent and severity of the physical impacts varied with soil characteristics, slope and climate as well as users. This study noted that the severity of the physical impacts appear less than the impacts recorded from other studies (Bjorkman 1996; Wöhrstein, 1998). This difference is attributed to different climate, soil characteristics and much lower use levels than in Wisconsin and Germany. The soils of the study area are lateritic and potentially less prone to erosion. However, other studies did not include these soil types and therefore the robustness of these soils needs to be confirmed, especially in situations with much higher levels of use. In this study, the total number of passes recorded by the counters were 342 at Lowden and 426 at Marrinup. This is the lower limit of riders, an order of magnitude less then user levels in other studies. In Bjorkman's study (1996) 3788 passes per month were recorded in one trail and 9849 passes on another trail, and Wöhrstein's study recorded 6000 passes. Nevertheless, nature-based tourism is increasing in Western Australia, especially in the southwest (Western Australia Tourism Commission, 1997), and if mountain biking on trails in parks and reserves continues to increase with this growth, the potential for environmental impacts will also increase. Therefore in a climate of precautionary management, trails should be located and designed in Western Austalia to conservative environmental requirements and to cater for much higher levels of use to ensure that the trails are sustained well into this century.

Clearly, the potential for erosion, soil compaction and trail widening needs to be considered when locating a mountain bike trail or a trail shared with walkers. Different design parameters may need to be used for these two types of trails since walkers cause higher compaction rates on downhill and flat sections compared to riders. Ideally, environmentally inappropriate areas should be avoided, but previous studies have shown that if the trail is not sited in areas that appeal to riders alternative trails will be formed. In Marin County, California, only wide trails and fire tracks were open to mountain bike riders, who subsequently established illegal trails (Edger, 1997). The option in cases where environmentally sensitive areas cannot be avoided is to ensure environmental impacts are minimised by avoiding steep downhill sections with tight curves and sandy areas. Water bars can be used to prevent erosion on hill section, but they should be placed so that they cannot be circumvented.

The nature of the trail surface needs to be considered in trail design since soil characteristics are directly related to erosion and compaction. In this survey, respondents did not respond positively to smooth surfaces, while Cessford's (1995a) study found that most riders preferred smooth surfaces. This study and his study, however, found that riders do not like overhanging branches, muddy or boggy areas and loose sand. Brindal and CALM (1995) found that riders preferred compacted or hard soils to gravel, sealed and rock surfaces. In this study gravel roads were acceptable to recreational riders only. The results of this study combined with the previous two studies suggest that trails can be designed to avoid erosion prone surfaces and easily meet rider preferences. In extreme situations where erosion is a problem other management measures such as trail hardening may be necessary.

Some respondents in this study remarked that a 'good' mountain bike trail has to have a wide variety of features to be interesting to ride on. This study found that trails should be technically challenging with a range of downhill sections, short uphill sections, curves and strategically placed logs. Trails should also have elements of excitement using steep slopes and jumps, especially if the trails are to be used by mountain bike racers. The need to provide a range of trail features coincides with other studies. Cessford (1995a) found essentially the same trends, with more experienced riders being more interested in technical difficulties, fast downhills and steep slopes as well as in racing. In addition to providing a variety of trail features, recreational riders also expressed the need for trail facilities, such as water and route markers. Brindal and CALM (1995) determined that the most important trail facilities were water and clear signposting. Chavez (1993) also found that riders wanted to have drinking water available at the trailhead.

Recreational riders and racers in this and other studies (Ruff & Mellors, 1993; Cessford 1995a; Hollenhorst *et al.*, 1995) expressed a preference for trails in natural settings and a clear avoidance of urban or built environments. In this study respondents also indicated that they were willing to travel greater distances to use trails in natural settings. Horn *et al.* (1994) found a number of respondents in their study were also urban riders. Riders in this study went out at least two to three times per week, while Wöhrstein (1998) noted riders rode an average of four times per week. The average distance travelled by riders ranged from more than 10km (this study) to 16.5km (Wöhrstein, 1998).

This study and Horn *et al.* (1994) indicated that there is a demand for mountain bike trails in natural settings close to urban centres. However, the availability of these settings is limited and in high demand by other trail users. There is also a clear demand for trails well away from urban centres, and often these trails are in parks and recreation reserves. On these trails, there are pulses of peak use followed by periods of limited use. The resources in most parks are limited and therefore development and maintenance of a single-use trail is often not feasible. The management response to these demands for trails in either natural setting is to develop dual or multiple-use trails (E. MacGregor, Trailswest, pers. comm. 1999). In addition, as mountain bike riding increases in popularity, so the demand for longer and more varied trails increases, especially long-distance touring trails (Wöhrstein, 1998; Cessford, 1995a). This is evident in the southwest of Western Australia where 12 respondents of this survey specifically requested such trails and other respondents indicated accessing a long-distance walking trail despite a ban on mountain bikes. In response to this demand, WAMBA together with Trailswest[1], and supported by the Great Southern Development Commission and Bikewest[3] secured funding for a plan for the first stage of such a trail.

The motivation of mountain bike riders is often enjoyment, fun and fitness in a nature-based setting as suggested in this study and others (Hollenhorst *et al.*, 1995; Ruff & Mellors, 1991). Socialising was also highlighted in this study and by Cessford (1995a). These motivations clearly indicate that riders do not seek a wilderness tourism experience or an isolated setting and that there is an expectation of encountering other people on the trail. Once riders are on the trail, they are willing to tolerate other users such as walkers and horse riders, however, they do not want to encounter cars or motor bikes. Other studies (Cessford, 1995a; Watson *et al.*, 1991; Wöhrstein, 1998) revealed similar perceptions and attitudes to other trail users.

The tolerance towards other non-motorised trail users suggests that multiple-use trails are acceptable to most mountain bike riders. Although mountain bike riders tolerate other users, the corollary may not be true and other studies have noted a number of user conflicts such as displacement, right of way and speed (Bjorkman, 1996). Brindal and CALM *et al.* (1995) found that walkers were less tolerant of other trail users including mountain bike riders. Conflict is often asymmetric, or one-sided, which means that one user group resents another user group, which in turn does not reciprocate these sentiments (Moore & Barthlow, 1997; Watson *et al.*, 1991). Consequently, trail designers need to consider these conflicts in multiple-use trails. Often an education or liaison programme complementing the establishment of such trails can reduce the conflicts between the different users (Chavez, 1996a, b; Moore, 1994).

Conclusion

Mountain bike riding in natural settings will only be sustainable if trails are located, established and managed in a manner that integrates the environmental sensitivity of the area and rider preferences. Environmental studies indicated that impacts such as soil compaction and erosion of the trail surface due to mountain biking on trails varies. Nevertheless, environmental changes are to be expected and they may not be problematic as long as they remain within the limits deemed acceptable for a trail. These conditions include maintaining a firm trail surface, avoiding trail widening and minimising erosion. These conditions appear to be obtainable through good trail placement, design and management. In the case of existing trails, trail hardening where there is extreme environmental damage, rider education and trail closures are some of the options available to managers.

The main environmental consideration is to place the trail where there are appropriate soils that can withstand the impacts created by mountain bikes and the avoidance of steep downhill sections, especially if the trail is shared with walkers. Where steep downhills cannot be avoided or are desired, erosion prevention measures (e.g. water bars) should be included at the planning stage. Consideration should be given to the inclusion of curves, which could reduce the steepness of a slope and effectively reduce its length. Care should be taken to ensure that the curves are designed in such a way that they do not add to the erosion potential through increased skidding.

Clearly where possible, mountain-bike-specific trails should be established to avoid conflicts with other trail users. Where this is not possible multiple-use trails can be developed, however, sharing of trails with motorised vehicles should be avoided. Multiple-use trails should be clearly marked as such and be carefully designed to ensure that the needs of all trail users are considered. In the case of unresolved user conflicts, management options ranging from user education to prohibition and user separation may be necessary.

Acknowledgements

Trailswest (especially Ewen MacGregor), CALM, WAMBA, Peel District Mountain Bike Club, the Thomas family and all volunteers and survey respondents are thanked for their participation in this study.

Correspondence

Any correspondence should be directed to Ute Goeft, Centre for Ecosystem Management, Faculty of Communication, Health and Science, Edith Cowan University, 100 Joondalup Drive, Joondalup 6027, Western Australia (u.goeft@ecu.edu.au).

Notes

1. Trailswest is a small but distinct unit within the Ministry of Sport and Recreation, charged with the responsibility for overseeing recreation trail development for non-motorised uses (walking, mountain biking and horse riding) in Western Australia. Website: http://www.msr.wa.gov.au (scroll to bottom of page and click on Trailswest logo)
2. 02 horizon = organic layer. A horizon = top soil.
3. Bikewest is a division within the Western Australian Ministry of Transport that continues to encourage cycling and bicycle education. Bikewest focuses on cycling promotion, education, research, information provision and facilitation of others to promote cycling. Website: http://www.transport.wa.gov.au/metro/bikewest

References

Bjorkman, A.W. (1996) *Off-road Bicycle and Hiking Trail User Interactions: A Report to the Wisconsin Natural Resources Board*. Wisconsin: Wisconsin Natural Resources Bureau of Research.

Blahna, D.J., Van Patten, S., Dawson. S.A., Reiter, D. and Von Koch, R. (no date; approx. 1994) Slickrock Trail mountain bike survey: Implications for resource managers and area communities. Unpublished paper supplied by Dale Blahna, Department of Forest Resources, Utah State University, Logan, UT 84322-5215.

Blahna, D.J., Vilter, J.C. and Von Koch, R. (1994) Slickrock/Sand Flats mountain biker study: Respondents characteristics and activity expenditures. Report prepared for Canyonlands Field Institute, supplied by Dale Blahna, Department of Forest Resources, Utah State University, Logan, UT 84322-5215.

Brindal, A. and CALM (1995) Perth to Albany bike track network – a proposal. Unpublished draft, Department of Conservation and Land Management, Western Australia.

CALM (1997) Mountain bikes on CALM estate, background on mountain biking. Unpublished background paper, Department of Conservation and Land Management, Western Australia.

CALM (1999). Policy statement no. 18 – draft. Recreation, Tourism and Visitor Services, Department of Conservation and Land Management, Western Australia.

Carrothers, P., Vaske, J.J and Donnelly, M.P. (1998) Social values versus interpersonal conflict. Powerpoint presentation supplied by J. Vaske, Department of Natural Resource Recreation and Tourism, Human Dimensions in Natural Resources Unit, Colorado State University.

Cessford, G.R. (1995a) Mountain biking impacts and rider preferences. *Proceedings of the New Zealand Recreation Association Conference, Mt. Cook, New Zealand* (pp. 61–71). http://www.mountainbike.co.nz/politics/.

Cessford, G.R. (1995b) *Off-road Impacts of Mountain Bikes: A Review and Discussion.* Wellington, New Zealand: Science and Research Series no. 92, Department of Conservation. http://www.mountainbike.co.nz/politics/.

Cessford, G.R. (1995c) *Off-road Mountain Biking: A Profile of Participants and their Recreation*

Setting and Experience Preferences. Wellington, New Zealand: Department of Conservation. http://www.mountainbike.co.nz/politics/.
Chavez, D., Winter, P., and Baas, J. (1993) Recreational mountain biking: A management perspective. *Journal of Park and Recreation Administration* 11 (1), 29–36.
Chavez, J.D. (1996a) Mountain biking: Direct, indirect, and bridge building management styles. *Journal of Park and Recreation Administration* 14 (4), 21–35.
Chavez, J.D. (1996b) *Mountain Biking: Issues and Actions for USDA Forest Service Managers*. Research Paper PSW-RP-226. Albany, CA: United States Department of Agriculture, Forest Service, Pacific Southwest Research Station.
Chavez, D. (1993) User perceptions about mountain biking in the San Jacinto region: A management and research partnership. Unpublished paper supplied by author, USDA Forest Service, Pacific Southwest Research Station.
Cole, D.N. (1983) *Assessing and Monitoring Backcountry Trail Conditions*. Research Paper INT-303. Ogden, UT: United States Department of Agriculture, Forest Service, Intermountain Research Station.
Coleman, R.A. (1977). Simple techniques for monitoring footpath erosion in mountain areas in north-west England. *Environmental Conservation* 4 (2), 145–8.
Deluca, T.H., Patterson, W.A., Freimund, W.A. and Cole, D.N. (1998) Influence of llamas, horses, and hikers on soil erosion from established recreation trails in Western Montana, USA. *Environmental Management* 22 (2), 255–62.
Department of Lands, Parks and Wildlife (1987) *Walk Track Management Manual: A Guide to the Construction and Maintenance of Walking Tracks*. Tasmania: Department of Lands, Parks and Wildlife.
Edger, C.O. (1997) Mountain biking and Marin Municipal Water District Watershed. *Trends* 34 (3), 5–10.
Ewert, A.W. (1989) *Outdoor Adventure Pursuits: Foundations, Models and Theories*. Ohio: Horizons Inc.
Goeft, U. and Alder, J. (2000) Mountain bike rider preferences and perceptions in the south-west of Western Australia. *CALM Science* 3 (2), 261–75.
Hawkins, J.P. and Roberts, C.M. (1993) The growth of coastal tourism in the Red Sea: Present and possible future effects on coral reefs. In *Proceedings of the Colloquium on Global Aspects of Coral Reefs: Health, Hazards and History* (pp. 385–91). Miami: University of Miami.
Hollenhorst, S.J., Schuett, M.A., Olson, D. and Chavez, D.J. (1995) An examination of the characteristics, preferences, and attitudes of mountain bike users of the National Forests. *Journal of Park and Recreation Administration* 11 (3), 41–51.
Horn, C., Devlin, P. and Simmons, D. (1994) Conflict in recreation: The case of mountain bikers and trampers. New Zealand: Department of Conservation. http://www.mountainbike.co.nz/politics/articles/horn.
Jacoby, J. (1990) Mountain bikes: A new dilemma for wildland recreation managers? *Western Wildlands* 16, 25–8.
Kirkegaard, I.R. and Gartside, D.F. (1998) Performance indicators for management of recreational fisheries. *Marine Policy* 22 (4–5), 413–22.
Lal, R. and Elliot, W. (1994) Chapter 8, Erodibility and erosivity. In R. Lal (ed.) *Soil Erosion Research Methods*. USA: Soil and Water Conservation Society and St Lucie Press.
Liddle, M. (1997) *Restoration Ecology – the Impact of Outdoor Recreation and Ecotourism*. London: Chapman & Hall.
Marsh, W.M. (1991) *Landscape Planning – Environmental Applications* (2nd edn). New York: John Wiley & Sons.
Mason, S.-A. and Moore, S.A. (1998) Using the Sorensen Network to assess the potential effects of ecotourism on two Australian marine environments. *Journal of Sustainable Tourism* 6 (2), 143–54.
McKercher, R. (1998). *The Business of Nature Based Tourism*. Melbourne: Hospitality Press.
Moore, R.L. (1994) *Conflicts on Multiple-use Trails: Synthesis of the Literature and State of the Practice*. Report No. FHWA-PD-94-031, US Federal Highway Administration.
Moore, R.L. and Barthlow, K. (1997) Principles for minimising trail conflicts: Applications to mountain biking. *Trends* 34 (3), 11–14.

Parker, D.B., Michel, T.G. and Smith, J.L. (1995) Compaction and water velocity effects on soil erosion in shallow flow. *Journal of Irrigation and Drainage Engineering* 121 (2), 170–8.

Priest, S. and Dixon, J. (1990) *Safety Practices in Adventure Programs*. USA: Association for Experimental Education.

Ruff, A.R. and Mellors, O. (1993) The mountain bike – the dream machine? *Landscape Research* 18 (3), 104–9.

Seney, J.P. and Wilson, J.P. (no date) *Erosional Impact of Hikers, Horses, Off-road Bicycles and Motorcycles on Mountain Trails*. Missoula, MT: USDA, Forest Service, Intermountain Research Station.

Sun, D. and Walsh, D. (1998) Review of studies on environmental impacts of recreation and tourism in Australia. *Journal of Environmental Management* 53 (4), 323–38.

Watson, A.E., Williams, D.R. and Daigle, J.J. (1991) Sources of conflict between hikers and mountain bike riders in the Rattlesnake NRA. *Journal of Parks and Recreation Administration* 9 (3), 59–71.

Wellington Regional Council (1996) *Wellington Regional Council Policy on Mountain Biking*. Wellington, New Zealand: Wellington Regional Council.

Western Australian Tourism Commission (1997) *Nature Based Tourism Strategy for Western Australia*. Perth, Western Australia: Western Australian Tourism Commission.

Widmer, M.A. (1997). Management through education. A mountain biking curriculum. *Trends* 34 (3), 22–25.

Wilson, J.P. and Seney, J.P. (1994) Erosional impact of hikers, horses, motorcycles, and off-road bicycles on mountain trails in Montana. *Mountain Research and Development* 14 (1), 77–88.

Wöhrstein, T. (1998) *Mountainbike und Umwelt – Ökologische Auswirkungen und Nutzungskonflikte* (Mountainbike and Environment – Ecological Impacts and Use Conflict). Saarbrücken-Dudweiler: Pirrot Verlag & Druck.

World Tourism Organisation (1998) Ecotourism: Now one-fifth of the market. *World Tourism News* 1 (1), 6.