Journal of Environmental Management 91 (2010) 551–562

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Review

Comparing hiking, mountain biking and horse riding impacts on vegetation and soils in Australia and the United States of America

Catherine Marina Pickering [a,*], Wendy Hill [a], David Newsome [b], Yu-Fai Leung [c]

[a] International Centre for Ecotourism, Griffith University, Gold Coast, QLD 4222, Australia
[b] Environmental Science and Ecotourism, Murdoch University, Murdoch, WA 6150, Australia
[c] Department of Parks Recreation and Tourism Management, North Carolina State University, Raleigh, NC 27695-7106, USA

A R T I C L E I N F O

Article history:
Received 6 July 2009
Received in revised form
15 September 2009
Accepted 21 September 2009
Available online 27 October 2009

Keywords:
Recreation ecology
Nature-based tourism
Impacts
Weeds
Horse riding
Mountain biking

A B S T R A C T

Hiking, horse riding and mountain biking are popular in protected areas in Australia and the United States of America. To help inform the often contentious deliberations about use of protected areas for these three types of activities, we review recreation ecology research in both countries. Many impacts on vegetation, soils and trails are similar for the three activities, although there can be differences in severity. Impacts include damage to existing trails, soil erosion, compaction and nutrification, changes in hydrology, trail widening, exposure of roots, rocks and bedrock. There can be damage to plants including reduction in vegetation height and biomass, changes in species composition, creation of informal trails and the spread of weeds and plant pathogens. Due to differences in evolutionary history, impacts on soil and vegetation can be greater in Australia than in the USA. There are specific social and biophysical impacts of horses such as those associated with manure and urine, grazing and the construction and use of tethering yards and fences. Mountain bike specific impacts include soil and vegetation damage from skidding and the construction of unauthorised trails, jumps, bridges and other trail technical features. There are gaps in the current research that should be filled by additional research: (1) on horse and mountain bike impacts to complement those on hiking. The methods used need to reflect patterns of actual usage and be suitable for robust statistical analysis; (2) that directly compares types and severity of impacts among activities; and (3) on the potential for each activity to contribute to the spread of weeds and plant pathogens. Additional research will assist managers and users of protected areas in understanding the relative impacts of these activities, and better ways to manage them. It may not quell the debates among users, managers and conservationists, but it will help put it on a more scientific footing.

1. Introduction

Australia and the United States of America (USA) are large countries of similar size (7 617 930 km^2 and 9 161 923 km^2, respectively) with communities that generally have the motivation and opportunity to conserve natural areas and engage in a range of recreational activities within them. Both countries have similar traditions in the establishment and management of protected areas. They have set aside large areas of public land for protecting natural resources (10.4%, 831 420 km^2 of Australia and 15.7%, 1 466 880 km^2 of the US) (Lockwood et al., 2006). Nature-based tourism and recreation is promoted as a legitimate and desirable use of many of these protected areas. However, as visitor use activities have a range of negative environmental impacts it is a constant challenge to protect natural resources while providing sustainable recreational opportunities (Cole 1987a, 2004a; Lockwood et al., 2006).

The USA has strong conservation and research traditions and scientists have been studying the biophysical impacts of recreation on the natural environment (recreation ecology) for close to a century. As early as the 1920s the impacts of human trampling on natural vegetation and soils were first investigated (Meinecke, 1928). In the 1970s a substantial body of recreation ecology literature began to accumulate paralleling a dramatic increase in visitation to protected areas (Hammitt and Cole, 1998; Liddle, 1997). The majority of researchers in the USA are currently working on developing impact indicators and feasible procedures to support monitoring programs as an essential component of visitor management efforts. Some of these indicators are related to

* Corresponding author. Fax: +61 7 5552 8067.
E-mail addresses: c.pickering@griffith.edu.au (C.M. Pickering), D.Newsome@murdoch.edu.au (D. Newsome), leung@ncsu.edu (Y.-F. Leung).

0301-4797/$ – see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jenvman.2009.09.025

conditions of formal trails and the extent of informal trails. A substantial portion of the recreation ecology literature has been generated by scientists in government agencies such as the US Forest Service, National Park Service and US Geological Survey (Cole, 2003).

In contrast to the USA, recreation ecology in Australia has lagged behind with fewer people, most of whom are in academia, undertaking research over a shorter timeframe and with less funding (Buckley, 2005). As a result there is around five times as many publications on the impacts of hiking, horses and off-road vehicles in North America (most in the USA) than there are in Australia and New Zealand (Buckley, 2005). Consequently, Australian managers and researchers often have to look to research from the USA as a substitute for Australian research. This can be misleading as recreation impacts on Australian ecosystems can be more severe than in the USA.

Differences in the evolution of soils, flora and fauna in Australia make Australian ecosystems more sensitive to some recreational impacts than those in the USA. Australian vegetation evolved in the absence of larger mammals, particularly hard hoofed herbivores such as sheep, goats, cattle and horses (Newsome et al., 2002). As a result many of Australia's ecosystems have lower resistance to trampling than ecosystems in other continents where hard hoofed animals are native. With the introduction of large grazing mammals in Australia by humans in the last 200 plus years, areas of native forest, woodland and grassland have been replaced by introduced pasture grasses that are more resilient to grazing, trampling, and eutrophication (Liddle, 1997; Newsome et al., 2002). Due to a long period of weathering Australian soils are often low in nutrients, particularly nitrogen and phosphorous (Hamblin, 2001; McKenzie et al., 2004; Thomson and Leishman, 2004). Therefore addition of these nutrients to soils from manure and urine alters some ecosystems, often favouring exotic plants over natives. Australia has had a long period of geographic isolation resulting in high levels of endemism in the biota (Williams et al., 2001). As a result, the introduction of plants, pathogens and feral animals from overseas, has dramatically affected most natural ecosystems. Indeed, invasive species are recognised as nationally threatening process for native biodiversity in Australia (Australian Government, 2009). Many weed invasions in Australian protected areas are a direct consequence of vegetation and soil disturbance and soil nutrient enrichment (Hobbs and Atkins, 1998). Similarly, tourism use of protected areas is a major factor in the spread of introduced pathogens such as the root-rotting fungus *Phytophthora cinnamomi* (Specht and Specht, 1999; Newsome, 2003; Buckley et al., 2004; Worboys and Gadek, 2004; Turton, 2005). This fungus is harmful to a wide range of native plants and is listed as a key threatening process by the Australian Government (Environment Australia, 2001).

Hiking, horse riding and mountain biking are common activities in Australian and USA protected areas. They occur on dedicated trails (hiking trails, bridle trails or specific mountain bike trails), on multi-use trails and/or off trail in backcountry/wilderness areas (Watson et al., 1993; Liddle, 1997; Goeft and Alder, 2001; Newsome et al., 2002, 2008; White et al., 2006). The appropriateness of conducting these activities in some locations is contentious because of their potential to degrade trails, natural vegetation and soils and disturb wildlife (Watson et al., 1993; Liddle, 1997; Marion and Wimpey, 2007; Newsome et al., 2008; White et al., 2006). While horse riding and mountain biking are often perceived as high impact activities, there is increasing pressure from user groups for increased access, particularly in reserves close to urban areas (Landsberg et al., 2001, Newsome et al., 2008; Newsome and Davies, in press; White et al., 2006; Webber, 2007).

Recreation ecology research has traditionally focused on understanding the range of environmental impacts from recreation. More recently researchers in both the USA and Australia have attempted to quantify the relative severity of impacts from specific activities (Cole, 2004a, b). The findings, and in some cases, methods used for this research have been questioned by the different user groups and conservation organisations (Landsberg et al., 2001; White et al., 2006; Webber, 2007; Newsome et al., 2008). Given this situation it is important to evaluate what is, and is not known, about the impacts of hiking, horse riding and mountain biking in protected areas. This includes what types of impacts have been found, their severity, if there are activity specific impacts, what indicators can be used to assess impacts, what methods are being utilised, analysis of methodological limitations to existing research, and what directions and methods should future research take to address the needs of users and of managers who are making decisions about recreational use in protected areas of Australia and the US. A comparative review of research in these two countries can shed light on other protected area systems in the world with respect to similar impact issues.

In order to conduct this review, we consulted all major recreation ecology references, a series of electronic databases and the authors own reference libraries to compile a comprehensive collection of empirical studies conducted in the USA and Australia that have found soil and vegetation impacts from hiking, horseback riding and mountain biking. A research method dataset was constructed by extracting relevant information from each reference.

2. Hiking impacts

Recreation ecology research in the USA and in Australia had been dominated by studies of hiking and camping impacts on vegetation and soil (Liddle, 1997; Buckley, 2005). The literature in the USA has been reviewed by Cole (1987a, 2004a) and Leung and Marion (2000) and in Australia by Liddle (1997) and Pickering and her colleagues (Pickering and Hill, 2007a, b; Hill and Pickering, 2009a, b, c). At least 33 studies in the USA have documented a range of impacts from hiking on soils and vegetation (Table 1). A major focus of the USA literature has been impacts of hiking on existing formal and informal trails. Out of 33 studies in the USA examining hiking impacts, 14 looked at soil erosion on trails, and 11 looked at the width of trails (Table 1).

We identified 26 studies from Australia that have examined impacts on vegetation and soils from hiking with most research either in mountain regions (Whinam et al., 1994; Whinam and Chilcott, 1999, 2003; Bridle and Kirkpatrick, 2003, 2005; Dixon et al., 2004; Bridle et al., 2006; Mende and Newsome, 2006; Pickering and Growcock, in press) or the subtropics (Sun and Liddle, 1993a, b; Hill and Pickering, 2009a) (Table 1). The Australian research also includes work on and off trail, but there appears to be a greater focus on the association between hiking and weeds than in the USA which will be discussed in more detail later.

Impacts of hiking found in Australia and the USA include soil compaction and loss, reduced soil moisture, loss of organic litter, loss of ground cover vegetation, loss of native plant species, introduction of weeds and pathogens, and change in vegetation composition (e.g. Leung and Marion, 2000; Randall and Newsome, in press) (Table 1). The relative impacts from different levels of hiking use, and use under different environmental conditions such as vegetation type, slope, soil type, season and weather conditions have also been examined in both countries (Cole and Bayfield, 1993; Cole, 1995a, b; Leung and Marion, 1996; Hill and Pickering, 2009a, b, c; Pickering and Growcock, in press).

A standardized experimental protocol for assessing trampling impacts on vegetation (Cole and Bayfield, 1993) has been used to

Table 1
Number of studies documenting specific impacts of hiking, mountain bike riding and horse riding conducted in Australia and the USA.

	Hiking		Mountain bike riding		Horse riding	
	Australia	USA	Australia	USA	Australia	USA
Trail degradation						
Soil erosion	7	11	3	4	2	7
Soil compaction	1	3	2	1		2
Change to trail width	5	10	1	3	2	2
Change to trail verge vegetation	7	2	2	1	1	
Increased muddiness	1	5				
Exposed roots/rocks	2	2	1			
Informal/social/constructed trails	3	3	2			
Mountain bike specific damage			2			
Horse specific damage					1	2
Degradation of natural vegetation and soils (e.g. off trail use)						
Change in organic litter	4	1				1
Soil erosion	4	6		1	2	2
Increase in bare soil	9	7		1	1	2
Soil compaction	1	4				1
Soil nutrients	3	1			1	
Soil microbial communities		1				
Change in plant species	5	4		1	1	
Change in native vegetation	8	11		1	2	2
Weeds	5					
Fungal pathogens	1	3		1		
Seed transported by	3				3	4

Details of impacts and each study provided in Appendix 1.

compare the effect of different intensities of hiking including in Australia and the USA (Hill and Pickering, 2009a). Hiking resistance indices: the number of passes by a hiker required to reduce vegetation cover by 50% (Liddle, 1997), have been documented for 55 vegetation types internationally (Hill and Pickering, 2009a). In the USA, hiking resistance indices are available for 28 vegetation types, ranging from 20 passes in a subalpine forest understory dominated by erect fern (Cole, 1995a) to 1000 passes in subalpine grasslands (Weaver and Dale, 1978). In Australia, hiking resistance indices have been documented for 10 vegetation types and range from 12 passes in *Eucalyptus* subtropical understory (Liddle, 1997) to 1475 passes in a far less resistant subtropical understory in the same region (Liddle, 1997; Hill and Pickering, 2009a). Across all the studies some general patterns are apparent, with hiking resistance declining from subtropical to alpine ∼ temperate ∼ subalpine ∼ arctic to montane and sand-dune grasslands to forest understorey and finally with heaths and herbfields the least resistant to hiking. Within each growth form and location there was still considerable variation in resistance indices, hence site specific research may still be required particularly for sites of high conservation value (Hill and Pickering, 2009a).

Much of the research on hiking impacts in the USA and in Australia has focused on easily observable soil and vegetation change with little research on indirect and cumulative effects. One important indirect impact of hiking that has cumulative effects is the spread of weeds. Once established in a protected area, environmental weeds can continue to spread even if there is no further tourism usage – that is they are a self-sustaining impact (Buckley, 2003; Pickering, in press). Trails act as corridors for dispersing exotic species into relatively pristine areas due to the altered environment on the trail and trail verge. This effect may be exacerbated by the type and amount of use. Hiking trail verges support a wide range of weed species, some of which have the capacity to spread into adjacent natural vegetation (Leung and Marion, 2000; Potito and Beatty, 2005; Pickering and Hill, 2007a, b). As part of a larger study on weeds in protected areas, the potential for clothing on hikers to act as vectors for seed has recently been reviewed (Pickering and Mount, in press). Socks and shoes were found to collect large amounts of seed, particularly when hikers walked on road and trail verges (Mount and Pickering, 2009). There seems to be limited research on this topic with only ten published studies on this topic (Mount and Pickering, 2009). Three of the studies were conducted in Australia (Wace, 1977; Whinam et al., 2005; Mount and Pickering, 2009), with the only US study conducted in Hawaii (Higashino et al., 1983). Based on the published research seed from 179 species of plants have been collected from clothing and equipment of which 43 are considered serious environmental weeds internationally (Mount and Pickering, 2009).

Human waste from hikers has biophysical and social impacts. For example, faeces and urine contain nitrogen and phosphorous at concentrations that can effect plant growth, particularly in sites with nutrient poor soils as occurs in many parts of Australia (Bridle and Kirkpatrick, 2003; Bridle et al., 2006). Research in Australia examining environmental and human impacts of human waste around hiking huts in temperate Tasmania, found that: (1) many people did not follow minimum impact codes and deposited faecal material close to huts; (2) there were peaks in nitrogen and phosphorous close to huts indicating that human waste was affecting soil nutrient levels; (3) the only changes in plant growth with increased nutrients around huts and in experimental urine addition, were increased growth in some native plants; (4) the rate of breakdown of toilet paper, tampons and faecal material varied among locations, with material still visible 1 year after deposition in some sites; and (5) there are human health and social issues with the presence of human waste from hikers, including reduced visual amenity and increased human pathogens occurring in local water bodies (Bridle and Kirkpatrick, 2003, 2005; Bridle et al., 2006).

Hiking can spread plant as well as human pathogens, particularly species of the highly invasive water molds (*Phytophthora*). In Australia *Phytophthora cinnamomi* is a major threat to native plants including many rare and threatened taxa (Newsome, 2003; Environment Australia, 2001). In the USA, *Phytophthora ramorum* is a highly invasive plant pathogen that causes sudden oak death in a range of tree species in California and Oregon (Cushman and Meentemeyer, 2008).

There is a clear association between hiking use of a region and the spread of *Phytophthora* in Australia and the USA (Newsome, 2003; Cushman and Meentemeyer, 2008). In Australia, *Phytophthora cinnamomi* is found on hiking trails in Western Australia (Newsome, 2003), Tasmania (Schahinger et al., 2003), New South Wales (Daniel et al., 2006), Victoria (Weste et al., 2002; Boon et al., 2008) and Queensland (Worboys and Gadek, 2004; Turton, 2005) where it often spreads into native vegetation. In the USA, *Phytophthora ramorum* is associated with hiking trails, and is more common in regions with higher visitation (Cushman and Meentemeyer, 2008). Hikers and vehicles have also been associated with spread of other *Phytophthora* species in the USA such as *Phytophthora lateralis* that causes root rot on Port Orford Ceder (Jules et al., 2002).

More direct evidence of hikers transmitting plant pathogens has been obtained. In the USA, samples of *Phytophthora ramorum* were obtained from around 40% of shoes of children hiking a 2.4 km trail in a protected area in California (Davidson et al., 2005). Studies have also found that *Phytophthora ramorum* is carried on the hikers shoes entering and leaving a protected area in California, with the distance the person walked on the trail increasing the chance of the pathogen being transported (Cushman et al., 2007). They also found that the pathogen was only viable for a relatively short time in soil on shoes (around 24 h if dry, 72 h if moist), indicating that hiking is likely to result in short term and/or localized dispersal. In southwest Western Australian ecosystems, however, once the pathogen *Phytophthora cinnamomi* is established it has the capacity to spread and become a serious ecological problem. The survival and spread of *Phytophthora cinnamomi* in southwest Western Australia is favoured by warm seasonally moist soil conditions (DWG, 2009). The pathogen is able to survive within plant root material under dry soil conditions. When conditions are favourable it can spread between plants by root-to-root contact (DWG, 2009). With around 2800 species of plant in southwest Western Australia susceptible to infection (Shearer et al., 2004) *Phytophthora cinnamomi* constitutes a major biodiversity and visitor use problem in protected areas.

3. Horse riding impacts

There are fewer studies on the biophysical impacts of horse riding than there on hiking (Table 1). We were able to find 12 papers on horse riding impacts in the USA and six in Australia (Table 1). Many types of impacts from horses are similar to those from hiking particularly soil compaction and erosion, loss of organic litter, loss of ground cover vegetation, loss of species, trail erosion and widening and potentially the spread of weeds and pathogens into natural vegetation (Table 1). What can differ is the severity of impacts. For example, the greater weight of horses can result in more damage to vegetation and soils than people hiking (Weaver and Dale, 1978; Liddle, 1997) while grazing by horses can result in more damage to grasses and other palatable species (Newsome et al., 2004, 2008; Cater et al., 2008).

Two types of impacts that are likely to be much greater from horse riding than the other activities are nutrification of soils and waterways from horse manure and the spread of weeds. In addition to the impacts due to human waste (Bridle and Kirkpatrick, 2003, 2005; Bridle et al., 2006) that would be associated with all three activities, horses themselves produce large amounts of waste. Horses manure (faeces and urine) contain nitrogen, phosphorous and various heavy metals (Edwards et al., 1999; Westendorf, 2009). In stables, farms, paddocks and natural areas, the management of horse waste is an important environmental issue particularly where it may contaminate waterways (Edwards et al., 1999; Westendorf, 2009). The amount of dung produced by an adult horse (400–600 kg body weight) per day is of the order of 17–26 kg, while for urine it is around 5–7 l per day (Mastsui et al., 2003). The addition of nutrients in horse manure is more likely to be an issue where soils are low in nutrients, particularly phosphorus such as many Australian soils (Newsome et al., 2004, 2008; Cater et al., 2008). Horse manure can introduce around 1 g of phosphorous and 2.5 g of nitrogen per horse per day (Westendorf, 2009). Along trails and tracks it can lead to local nutrient hotspots. In tethering areas or other places where horse densities are higher the amounts of nutrients added can start to affect local vegetation favouring species adapted to higher nutrients (Mouissie et al., 2005; Westendorf, 2009). It can also increase the risk of runoff into local water ways affecting riverbank and aquatic biota (Edwards et al., 1999; Westendorf, 2009).

In addition to any seed transported by horse riders, saddles, floats and vehicles, horses have the potential to spread seed via their coats, hoofs and most of all in dung. Horses can eat seed that have been found to be viable from dung for up to 10 days post ingestion (St John-Sweeting and Morris, 1991). As some of the seed they eat comes from species that can be invasive in protected areas, horses may be bringing new species into protected areas. Internationally there are at least 11 studies examining seed in horse manure of which four were in the USA (Campbell and Gibson, 2001; Wells and Lauenroth, 2007; Gower, 2008; Quinn et al., 2008), and three in Australia (St John-Sweeting and Morris, 1991; Whiman et al., 1994; Weaver and Adams, 1996). Based on all 11 studies, seed from 216 species is known to be viable after passing through the digestive tracks of horses, 45 of which are serious intentional environmental weeds (Pickering and Mount, in press). What is not currently less clear is if these species germinate *in situ*, become established and spread in protected areas. There do not appear to be any Australian or USA field studies confirming that weed species germinate *in situ* from horse manure along trails in protected areas (Table 1). Nonetheless, the environmental weed *Ehrharta calycina* has been observed by one of the authors (Newsome) germinating from dung deposited by horses on walk trails traversing weed free natural vegetation in John Forrest National Park, Western Australia.

Studies in Europe have confirmed that such seed can germinate from horse dung in a range of environments (Mouissie et al., 2005; Törn et al., 2009). A field study in subalpine Tasmania found that weed seed did not germinate from manure along trails, but did germinate from horse dung in field plots where soil and vegetation were disturbed (Whinam and Comfort, 1996). In contrast, weeds did not germinate from manure or hoof debris samples along trails in the eastern USA (Gower, 2008). The potential for horses to disperse weed seed and facilitate weed establishment and spread along trails and subsequently into natural vegetation in protected areas clearly needs further research.

We have not been able to find any studies that directly tested horse's hooves as dispersal mechanisms for plant pathogens such as *Phytophthora* in Australia or the USA. However, horse riding is considered to be an important risk factor for many protected areas as the pathogens have been transported on the tires of vehicles, and on human shoes (Newsome et al., 2002, 2008). Therefore, the spread of the pathogens may result from horse riding as an activity in protected areas even if horses themselves are not the primary vector.

4. Mountain biking impacts

Mountain biking is an increasingly popular activity in both relatively remote areas and urban-proximate conservation reserves and parks (Goeft and Alder, 2001; Schaefers, 2006; White et al., 2006; Marion and Wimpey, 2007; Davies and Newsome, 2009; Newsome and Davies, in press). Mountain biking is not homogenous. There are different riding styles including cross country, down hill, free and dirt jumping (Felton, 2004; Schaefers 2006; Webber, 2007; Newsome and Davies, in press). Although individuals may participate in several styles of mountain biking, what equipment they use, where they go, what facilities they expect and the likely impacts of their use can differ (Felton, 2004; Schaefers, 2006; Webber, 2007; Newsome and Davies, in press). Like hiking and horse riding, mountain biking can occur on multi-use, single use, informal trails or even on sites with no existing trails. Differences in the level of modification of the tracks and in riding styles are likely to affect the severity and types of impacts (Felton, 2004; Webber, 2007; Newsome and Davies, in press).

There is very little published research on biophysical impacts of mountain biking, as was highlighted recently in a review by Marion and Wimpey (2007). Research in Australia by one of the authors (Newsome) adds to this sparse literature. As a result, we were able to identify six studies in the USA and four studies in Australia that have examined the biophysical impacts of mountain biking (Table 1). We have included a Canadian paper (Thurston and Reader, 2001), as it is relevant to the likely impacts in the temperature regions of the US.

Studies in the USA have primarily focused on soil erosion and degrading trail conditions from mountain biking activities. One of the earliest studies on mountain biking impacts was conducted in a national forest in Montana (Wilson and Seney, 1994).

By employing a quasi-experimental design with 66 by 66 cm sample plots and low level simulated rainfall events, the researchers found that mountain biking generated less sediments from trails than horses and hikers. These results are somewhat supported by a recent study in southwestern USA (White et al., 2006) as mountain bike trails were found to be similar to hiking and multi-use trails with respect to trail impact indicators such as width, incision and cross sectional area indicative of soil loss. In the north-central state of Wisconsin, Bjorkman (1998) conducted a two-part study on the impacts of mountain bike trails. First he compared a surface-treated bike trail with an untreated bike trail by measuring sediment yield after natural rainfall events over 2 months. He found that the treated trail had only 1% of the amount of erosion that occurred on the untreated trail. The second part of Bjorkman's (1998) study involved examining biophysical changes on newly opened mountain bike trails in a state forest over five seasons. The results indicate that soil and vegetative changes on trail treads occurred rapidly initially and then tapered off, exemplifying the curvilinear use-impact relationship found in past research (Hammitt and Cole, 1998). The amount of soil erosion, as measured by cross section area and centerline depth, was not significant over the study period (Bjorkman, 1998). Slope was identified as the most important factor in influencing the changes in trail condition while the level of use did not play a significant role.

Recent work by Davies and Newsome (2009) and Newsome and Davies (in press) in Western Australia, in contrast, found a range of specific social and biophysical impacts arising from mountain biking. These include trail impacts such as erosion from skidding, linear rut development, user conflict and the addition of unauthorized constructed features to existing trail networks. In addition, a number of off trail impacts were identified including the creation of informal trails, creation of constructed features (technical trail features) along with reduced amenity. There is potentially a significant cost associated with this when management has to respond to such impacts. Furthermore, multiple linear rut incision, the systematic addition of technical trail features and informal trail development with amended trail surfaces are mountain bike specific impacts (Davies and Newsome, 2009; Newsome and Davies, in press).

The extent and severity of mountain biking impacts appears to be connected with different riding styles. Impacts are likely to be greater when riding is faster, less controlled, occurs on steeper slopes and in wetter conditions. In Western Australia impacts from different styles of bike riding were compared on trails (Goeft and Alder, 2001). Trail erosion and widening, soil compaction and vegetation damage on a recreational bike trail and a racing trail were recorded over 1 year in the wet and the dry season. Impacts were confined to the trail centre with few impacts to trailside vegetation, which is consistent with a past USA study (Bjorkman, 1998). Although the racing trail was wider after an event there was no widening over the longer term. The authors concluded that even though bike riders prefer downhill runs, steep slopes, curves and water stations (features related to higher impacts), mountain biking is sustainable so long as that trails are appropriately designed, located, and managed. The problem with such a conclusion, however, is that mountain biking often occurs on multiple use trails and in areas not designed for biking (Newsome and Davis, in press).

In contrast to the findings of Goeft and Alder (2001) Newsome and Davies (in press) identified mountain bike related impacts to be a significant management problem both on and off trails. Impacts included the deliberate modification of existing trail networks and the creation of informal trails. A global positioning systems (GPS) mapping tool was used to survey the location of trails used for mountain biking and constructed technical features. The area impacted by bikes was quantified and in just one small area bikers had created an informal trail network 2.54 km in length and cleared 2540 m^2 of forest in the development of informal trails. These impacts relate to particular riding styles and especially the thrill seeking adventure components of downhill riding, free riding and dirt jumping. Although this method was found to be useful for assessing mountain bike specific impacts and especially the impacts of informal trail development by mountain bikers it is not suitable for comparing the relative impacts of different use types on multi-use trails.

Damage to vegetation and soils from mountain biking are likely to favour weeds, as occurs with hiking and horse riding, however, there appear to be no studies documenting weeds on tracks used for mountain biking. Similarly, no studies examining mountain bikes as seed vectors have been found in extensive searches of the scientific literature (Pickering and Mount, in press). Clearly bikes have the potential to act as vectors for the transport of weed seed as studies on vehicles as vectors indicate that seed from over 505 species can be transported over long distances by vehicles (Pickering and Mount, in press).

Mountain bike tires have been found to carry *Phytophthora* spores in the USA (Cushman et al., 2007). It is likely the mountain bike riding is also a vector for root rot in Australia, although we have not found any studies that have directly examined mountain bikes in Australia. In the case of accessing natural areas over long distances, especially if it involves an overnight stay, mountain bike riders, like horse riders and hikers are likely to also deposit human waste which may have a range of biophysical impacts on the environment, but we have found no studies directly assessing this impact of riders. Moreover, there is the potential for the compounding problem of informal campsite development in some situations.

5. Comparative studies on relative impacts of hiking, horse riding and mountain biking

Researchers, protected area managers and some user groups agree on the need for more experimental research on the relative impacts of hiking, horse riding and mountain biking on trails, natural vegetation and soils (Cole and Spildie, 1998; Marion and Wimpey, 2007; Newsome et al., 2008; Newsome and Davies, in press, Webber, 2007). Impacts that have been experimentally compared to date are those that are common to all three activities; vegetation loss, species richness, soil exposure and trail degradation (erosion and widening) (Table 2). Several USA studies report that even low levels of horse use results in more severe impacts to soils, vegetation and trails than from hikers or other users (Table 2). Differences were due to the greater weight per unit area of a horse and rider compared to a person. For example, the pressure per unit area of a horse and rider can be ten times greater than for a person walking (around 4380 g cm^2 for a horse compared to 416 g cm^2 for a person in walking boots) (Liddle, 1997). Four studies have compared horse traffic impacts with hiker impacts; two in natural vegetation (Weaver and Dale, 1978; Cole and Spildie, 1998) and two on existing trails (Wilson and Seney, 1994; DeLuca et al., 1998). There appear to be no experimental comparative studies of horse and hiker impacts in Australia.

There are few studies on the relative impacts of mountain biking versus hiking in these two countries. Just three studies were found, two from North America and one from Australia (Table 2). Under the conditions tested, researchers found no evidence that mountain bike impacts to soils, vegetation and trails were significantly greater than impacts from hikers. Methodological issues, however, may limit the inferences that can be made from some of the results.

Table 2
Details of comparative studies of hiking (H), mountain bike riding (MR) and horse riding (HR) environmental impacts conducted in protected areas.

Source	H	MB	HR	Methods	Other uses tested	Location	Soil and vegetation impact indicators
DeLuca et al. (1998)	*		*	Exp. trampling on trails	Llamas	Lubrecht Experimental Forest, Montana, USA	Sediment yield, soil bulk density, soil roughness
Wilson and Seney (1994)	*	*	*	Exp. trampling on trails	Motor cycles, off-road vehicles	Gallatin National Forest, Montana, USA	Soil erosion (water runoff and sediment yield after simulated rainfall)
Chiu and Kriwoken (2003)	*	*		Exp. trampling on trails		Wellington Park, Tasmania, Australia	Soil erosion (change in trail surface elevation)
Weaver and Dale (1978)	*		*	Exp. trampling, natural veg.	Motor cycles	Rocky Mountains, USA	Bare width and depth of trampling lane, Bare ground (%)
Cole and Spildie (1998)	*		*	Exp. trampling, natural veg.	Llama	Lolo National Forest, Montana, USA	Relative cover mineral soil, vegetation, Relative veg. height
Thurston and Reader (2001)	*	*		Exp. trampling, natural veg.		Boyne Valley Provincial Park, Ontario, Canada	Relative bare mineral soil, relative cover (plant stem density), species richness
Olive and Marion (2009)	*	*	*	Field survey of trails (ps)	ATV	Big South Fork National River and Recreation Area, Kentucky/ Tennessee, USA	Cross sectional area of soil loss (subsample), trail width, depth
Törn et al. (2009)	*		*	Field survey of trails (ps)	Skiing	Oulanka National Park and Ruka Ski Resort Finland	Trail width, depth (centre, edges), Veg. cover (%) shrubs, forb and graminoids, bryophytes (%), presence of species
White et al. (2006)		*		Field survey of trails (ps)		Five ecological regions in Southwest USA	Trail width and depth (maximum),
Summer (1980, 1986)	*		*	Field survey of trails (ps)		Rocky Mountain National Park, Colorado, USA	Trail width, depth

Exp. = experimental, veg. = vegetation, ps = point sampling.

Only one study compared all three activities. Under quasi-experimental conditions erosion from hikers, horses, motors cycles, and off-road bikes on trails were compared on trails in Montana (Wilson and Seney, 1994). One hundred passes of each use type were applied to 108 trail sample plots, simulated low level rainfall was applied and sediment and water runoff collected and used as the correlate for trail erosion. Only horses caused significantly more sediment yield than control sites, under both wet and dry conditions. The authors concluded that mountain bikes caused no more erosional damage to trails than hikers. There are a number of methodological problems with this experiment. Prior to the experiments there were statistically significant differences in sediment yield behaviour between the hiker and off-road bicycles trails. As a result there was less sediment available for detachment and entrapment on hiker plots than on those for bikers. Also the simulated rainfall used was only equivalent to one third of natural rainstorms, and hence may not have had enough kinetic energy to properly test for differences in erosion among the three activities.

Experimental hiking and mountain biking were compared in natural understory vegetation in Ontario, Canada (Thurston and Reader, 2001). No significant differences were found in three indicators; vegetation cover, exposed mineral soil and species richness. The experiment provided little opportunity for breaking, accelerating or turning, however, and hence may only reflect ‘optimal’ riding behaviour.

Experimental hiking and biking were compared on an abandoned fire road in Tasmania, Australia (Chiu and Kriwoken, 2003). No significant differences were found in erosion from low impact bike use (bike riding without skidding on flat parts of the trail and on corners) and hiking. Again the results may only be relevant to situations in which trails are already hardened by previous use, and where riding behaviour is optimal.

Non-experimental track surveys have been used to assess the condition of trails predominantly used for hiking, horse riding and mountain biking. Surveys of this type have the underlying assumption that there is causal relationship between predominant use and track condition. Differences in condition among trails, however, may be the result of differences in the location of the trails (soil type, slope, vegetation type, etc.) and on maintenance regime rather than the predominant use. For example, trail width and erosion were recorded at transects systematically located along 126 km of trails in a recreation reserve in Kentucky and Tennessee (Marion and Olive, 2006; Olive and Marion, 2009). Trails were used predominantly for hiking (42 km), horse riding (44.2 km), mountain biking (3 km) or ATVs (all terrain vehicles). A bike trail was reported as having the least erosion, while horse and ATV use were associated with greater soil loss than either hiking or mountain biking. However, use of the bike trail was deemed to be low to moderate and furthermore the bike track was considered to be a specialised trail in terms of the design, soil type, trail position and grade. This track also received regular maintenance from a local bike club. Thus, the result may not apply to other biking trails that are less well maintenance and/or experience heavier use.

An extensive survey of trail conditions in the southwest US reported the average width and depth (erosion) of 262 km of trails primarily used by bikers (White et al., 2006). These data were compared with trail erosion and width data reported in Marion and Leung's (2001) study of hiking trails in the Great Smoky Mountains National Park. Although it was concluded that trails used for mountain biking in the southwest US had similar width and depth to trails receiving little or no mountain biking these are not statistically valid comparisons as data were not collected in a way that would allow such a comparison to be made.

6. Key gaps and future research directions

Based on existing research it is already possible to make some generalisations on hiking impacts. Further information on resistance and resilience of vegetation communities to trampling impacts of hikers will still be required in many instances, particularly for sites of high conservation value, and/or to assist in policy formation, when the use of a site for hiking is particularly controversial (Hill and Pickering, 2009b). The increasing popularity of adventure activities such a cross country hiking, rogaining and competitive sporting events such as cross country running, mean that there is still more to learn.

Research on horse riding and mountain biking is still limited compared to hiking contributing to the divisive nature of the debate about among user groups, managers and conservationists. One of the most obvious research needs is quantitative research experimentally testing the relative susceptibility of various environments to horse riding and mountain biking similar to that already available for hiking. This includes studies using standardised experimental methods such as those developed by Cole and Bayfield (1993) to assess trampling impacts. Similarly, two and three way comparative studies among hiking, horse riding and mountain biking are needed including using the standardised experimental methods. Quantitative experimental comparative studies can directly test the relative impact of different activities at given levels of use in specific sites. Data from such studies provide more reliable information and are particularly important in sites of high conservation value, of low resistance and resilience to disturbance, and where uses is particularly controversial. Another issue that can be addressed both experimentally and using surveys is assessing impacts relating to the distance travelled by horse riders and mountain bikers compared with other users and how this might extend trail erosion into areas not often assessed.

The majority of research in Australia and the US has shown that horse riding has the potential to cause degradation even at low levels of use (Tables 1 and 2). Impacts associated with group events including endurance, musters and cross country competitions also need to be examined. In addition to the research described above examining impacts in common to different activities, further research is required on horse riding specific impacts. These include research on impacts from grazing and nutrificiation due to horse manure, particularly in environments with low nutrient soils.

There is even less research on mountain biking than on horse riding. Research on mountain biking needs to address some of the methodological issues raised with past studies. For example, the riding styles of bikers in experimental studies needs to be more realistic. Studies comparing different styles of mountain biking will help identify what aspects of riders behaviour contribute to impacts. Skidding and breaking are more likely to result to soil detachment, the formation of ruts and V shaped grooves down the centre line of the trail or multiple tyre ruts especially in wet trail segments than riding straight on a flat surface. It is likely that some styles of riding may only be appropriate in highly modified designated sites in some parks and may not be appropriate at all in other parks. Mountain bike specific impacts have rarely been assessed including the construction and use of trail technical features such as unauthorized jumps, bridges and ramps as well as the creation of informal trails. Another fruitful avenue of research is to evaluate the effectiveness of alternative design or erosion control measures to reduce impacts on mountain bike trails (Bjorkman, 1998).

Research into the attitudes and motivations of mountain bikers and the role of interpretation and communication between bikers and park managers is required to parallel that for hikers and horse riders (Bjorkman, 1998). Successful examples of collaboration between mountain bikers and protected area managers in the design, construction, maintenance and use of mountain bike specific trails highlight how collaborative approaches have worked well in some instances (CALM, 2007; Webber, 2007; Naturebase, 2007; USDI, 2002).

Methods to monitor mountain bike and horse riding specific trails could be modified from those currently used for hiking trails (Pickering, 2008; Hill and Pickering, 2009b, c). For these single use trails, impacts can be related back to the users, and even quantified compared to levels of use. An issue that is likely to remain challenging is how to assess the relative impact of different user groups on multi-use trails (Pickering, 2008). Activity specific impacts may be apparent, but not impacts that are common to different activities, even if their severity may vary among user groups.

Further research into the potential of mountain bikes, horses and people to act as vectors for weed seeds and to cause environmental disturbance that favours weeds is required. Despite the considerable literature documenting the presence of weeds on roads and trails in protected areas (e.g. Tyser and Worley, 1992; Potito and Beatty, 2005; Pickering and Hill, 2007a, b; Mallen-Cooper and Pickering, 2008), there is a lack of experimental studies assessing the direct and indirect role of hikers, horse riders and mountain bikers in their introduction and spread. The presence of viable seed from a large numbers of invasive species in the dung of horses suggests that they are an important vector.

More research on impacts from human waste on the environment as well as those on human health and the social amenity of sites is also required for all three actives (Bridle and Kirkpatrick, 2003, 2005; Bridle et al., 2006). The methods used in the Australian studies of hikers could be replicated for the other two activities, and used in other locations in Australia and in the USA.

The limited activity specific research on mountain bikes, hikers and horse riders as dispersal agents for pathogens other than in human and horse faecal material is a major gap in the literature. Some research on mountain bikers and hikers in the USA indicates that they are dispersal agents (Cushman et al., 2007), and further work is needed to better quantify the risks associated with these activities in Australia and the USA. This could involve directly sampling for *Phytophthora*, or using surrogates such as fluorescent powders, to determine relative risk and potential dispersal distances.

7. Conclusions

Biophysical impacts from hiking are better researched than from horse riding and mountain biking. There are impacts in common to all three activities, although differences in the severity of the impact, with horse riding appearing to have greater impacts per user than hiking. For mountain biking it is hard to assess relative impacts as there is little research, particularly using quantitative experimental methods and more realistic riding styles. There are activity specific impacts that can damage the environment, but again further research is required. We hope that this review helps managers, researchers, users and conservation organisations by highlighting what is known, even if a significant finding is, that there is still much more we need to find out.

Acknowledgments

Research by three of the authors (Hill, Newsome and Pickering) was supported by the Sustainable Tourism Cooperative Research Centre, Griffith University. The final author (Leung) has received funding support from the USA National Park Service.

Appendix 1

Details of studies that have documented specific impacts of hiking, horse riding, mountain biking on natural vegetation soils and trails in Australia and the US. * Study actually undertaken in Canada

	Hiking		Mountain bike riding		Horse riding	
	Australia	USA	Australia	USA	Australia	USA
Trail degradation						
Soil erosion	Calais and Kirkpatrick (1986)	Cole (1983, 1991)	Chui and Kriwoken (2003)	Bjorkman (1998)	Gillieson et al. (1987)	Deluca et al. (1998)
– Sediment yield and runoff	Chui and Kriwoken (2003)	Cole and Monz (2002)	Day and Turton (2000)	Marion and Olive (2006)	Whinam and Comfort (1996)	Marion and Olive (2006)
– Cross sectional area	Dixon et al. (2004)	Deluca et al. (1998)	Goeft and Alder (2001)	White et al. (2006)		Olive and Marion (2009)
– Track surface profile	McDougall and Wright (2004)	Jewell and Hammitt (2000)		Wilson and Seney (1994)		Weaver et al. (1979)
– Maximum trail depth	Mende and Newsome (2006)	Leung and Marion (1999a,b)				Wilson and Seney (1994)
– Lineal extent and location of excessive erosion	Scott and Kirkpatrick (1994)	Marion and Olive (2006)				Summer (1980, 1986)
– Categorical rating of erosion	Whinam and Chilcott (1999, 2003)	Marion and Leung (2001) Olive and Marion (2009) Summer (1980, 1986) Weaver et al. (1979) Wilson and Seney (1994)				
Soil compaction	Dixon et al. (2004)	Deluca et al. (1998)	Day and Turton (2000)	Bjorkman (1998)		Deluca et al. (1998)
– Bulk density		Summer (1980)	Goeft and Alder (2001)			Weaver et al. (1979)
– Reduced water infiltration rate		Weaver et al. (1979)				
Trail width	Calais and Kirkpatrick (1986)	Cole (1983, 1991)	Goeft and Alder (2001)	Bjorkman (1998)	Gillieson et al. (1987)	Marion and Olive (2006)
– Maximum width of trail (bare of vegetation)	Dixon et al. (2004)	Cole and Monz (2002)		Marion and Olive (2006)	Whinam and Comfort (1996)	Summer (1980)
– Maximum width of trail (bare plus impacted trailside vegetation)	McDougall and Wright (2004)	Leung and Marion (1999a,b)		White et al. (2006)		
– Categorical trail rating	Mende and Newsome (2006) Scott and Kirkpatrick (1994)	Marion (2007) Marion and Leung (2001) Marion and Olive (2006) Summer (1980) Weaver et al. (1979) Wilson and Seney (1994)				
Trail verge vegetation	Dixon et al. (2004)	Weaver et al. (1979)	Day and Turton (2000)	Bjorkman (1998)	Whinam and Comfort (1996)	
– Native cover, height and diversity	Hill and Pickering (2006)	Tyser and Worley (1992)	Goeft and Alder (2001)			
– Weed cover and diversity	McDougall and Wright (2004)	Zabinski et al. (2000)				
– Introduction of pathogens	Johnston and Pickering (2001)					
– Soil seed bank composition	Scott and Kirkpatrick (1994) Mallen-Cooper 1990 Mallen-Cooper and Pickering (2008)					
Muddiness	Mende and Newsome (2006)	Cole (1983, 1991)				
– Presence of excessive muddiness on trail		Leung and Marion (1999a)				
– Lineal extent and location of excessive muddiness		Marion (2007) Marion and Olive (2006)				

Appendix 1 (*continued*)

	Hiking		Mountain bike riding		Horse riding	
	Australia	USA	Australia	USA	Australia	USA
Exposed roots/rocks	Dixon et al. (2004)	Leung and Marion (1999a)	Day and Turton (2000)			
– Lineal extent and location of exposed roots on trail	Mende and Newsome (2006)	Marion and Olive (2006)				
Informal/social/constructed trails	Dixon et al. (2004)	Cole (1983, 1991)	Day and Turton (2000)			
– Area of	Mende and Newsome (2006)	Leung and Marion (1999a)	Newsome and Davies (in press)			
– Location of	Hockings and Twyford (1997)	Marion and Olive (2006)				
– Number of						
– Number and location of switchbacks						
Mountain bike specific damage on trails			Newsome and Davies (in press)			
– Trail technical features (jumps, bridges, switchbacks etc						
Horse specific damage on trails					Phillips and Newsome (2002)	Campbell and Gibson (2001)
– Vegetation cropping						Gower (2008)
– Tree trunk damage						
– Horse manure						
Degradation of natural vegetation and soil						
Organic litter	Liddle and Thyer, (1986)	Hartley (2000)				Hammitt and Cole (1998)
– Cover	Talbot et al. (2003)					
	Whinam and Chilcott (1999, 2003)					
Soil erosion	Liddle and Thyer (1986)	Cole (1987b, 1995ab)		Bjorkman (1998)	Phillips and Newsome (2002)	Cole and Spildie (1998)
– Topography	McDougall and Wright (2004)	Cole and Bayfield (1993)			Whinam et al. (1994)	Weaver and Dale (1978)
– Sediment runoff	Whinam and Chilcott (1999, 2003)	Cole and Monz (2002)				
– Depth of experimental plot		Hartley (2000)				
– Width of experimental plot		Weaver and Dale (1978)				
Bare soil	Pickering and Growcock (in press)	Cole (1987b; 1995ab)		Thurston and Reader (2001)*	Whinam et al. (1994)	Weaver and Dale (1978)
– Relative bare area	Hill and Pickering (2008)	Cole and Bayfield (1993)				Cole and Spildie (1998)
– % bare area	Hockings and Twyford (1997)	Cole and Spildie (1998)				
	Liddle and Thyer (1986)	Hartley (2000)				
	McDougall and Wright (2004)	Monz (2002)				
	Sun and Liddle (1993ab)	Monz et al. (2000)				
	Talbot et al. (2003)	Weaver and Dale (1978)				
	Whinam and Chilcott (1999, 2003)					
– Soil compaction	Talbot et al. (2003)	Hartley (2000)				
– Bulk density		Monz (2002)				Weaver and Dale (1978)
– Reduced water infiltration		Monz et al. (2000)				
		Weaver and Dale (1978)				
Soil nutrients	Bridle and Kirkpatrick (2003, 2005)	Monz (2002)			Phillips and Newsome (2002)	
– Nutrient addition	Bridle et al. (2006)					
Soil microbial communities		Zabinski and Gannon (1997)				
Species	Pickering and Growcock (in press)	Hartley (2000)		Thurston and Reader (2001)*	Phillips and Newsome (2002)	
– Number of species	Hill and Pickering (2008)	Thurston and Reader (2001)				

(*continued on next page*)

Appendix 1 (*continued*)

	Hiking		Mountain bike riding		Horse riding	
	Australia	USA	Australia	USA	Australia	USA
– Soil seed bank	McDougall and Wright (2004) Sun and Liddle (1993ab) Pickering and Hill (2007)	Willard et al. (2007) Zabinski et al. (2000)				
Vegetation	Hill and Pickering (2008)	Cole (1987b; 1995a)		Thurston and Reader (2001)*	Whinam et al. (1994)	Weaver and Dale (1978)
– Relative cover	Hockings and Twyford (1997)	Cole and Bayfield (1993)			Phillips and Newsome (2001)	Cole and Spildie (1998)
– Relative height	Pickering and Growcock (in press)	Cole and Spildie (1998)				
– Plant stem density	McDougall and Wright (2004)	Hartley (2000)				
– Area impacted	Sun and Liddle (1993a,b)	Monz (2002)				
– Biomass	Ross (2006) Talbot et al. (2003) Whinam and Chilcott (1999, 2003)	Monz et al. (2000) Ross (2006) Thurston and Reader (2001) Weaver and Dale (1978) Willard et al. (2007)				
Weeds	Hill and Pickering (2008)					
– Number of species	Pickering and Growcock (in press)					
– Relative cover	McDougall and Wright (2004) Sun and Liddle (1993a,b)					
Fungal pathogens	Newsome 2003	Cushman and Meentemeyer (2008) Davidson et al. (2005) Cushman et al. (2007)		Cushman et al. (2007)		
Weed seed collection/germination						
Seed collected from	Wace (1977)				Weaver and Adams (1996)	Campbell and Gibson (2001)
– Horse dung	Whinam et al. (2005)				Whinam et al. (1994)	Gower (2008)
– Horse coats, hooves	Mount and Pickering (2009)				St John-Sweeting and Morris (1991)	Wells and Lauenroth (2007)
– Peoples clothing						Quinn et al. (2008)

References

Government, Australian, 2009. Listed key threatening process. Available at. http://www.environment.gov.au/cgi-bin/sprat/public/publicgetkeythreats.pl Last Visited 31 March 2009.

Bjorkman, A.W., 1998. Biophysical Impacts on and User Interactions with Mountain Bicycle Off-road Trail Corridors. PhD Dissertation. University of Wisconsin, Madison.

Boon, P.I., Fluker, M., Wilson, N., 2008. A ten-year study of the effectiveness of an educative programme in ensuring the ecological sustainability of recreational activities in the Brisbane Ranges National Park, South-eastern Australia. Journal of Sustainable Tourism 16, 681–697.

Bridle, K.L., Kirkpatrick, J.B., 2003. Impacts of nutrient additions and digging for human waste disposal in natural environments, Tasmania, Australia. Journal of Environmental Management 69, 299–306.

Bridle, K.L., Kirkpatrick, J.B., 2005. An analysis of the breakdown of paper products (toilet paper, tissues and tampons) in natural environments, Tasmania, Australia. Journal of Environmental Management 74, 21–30.

Bridle, K., Kirkpatrick, J., von Platen, J., 2006. Human Waste Contamination at Huts and Campsites in the Back Country of Tasmania. Sustainable Tourism Cooperative Research Centre, Griffith University, Gold Coast.

Buckley, R., 2003. Ecological indicators of tourism impacts in Parks. Journal of Tourism 2, 54–66.

Buckley, R., 2005. Recreation ecology research effort: an international comparison. Tourism Recreation Research 30, 99–101.

Buckley, R., King, N., Zubrinich, T., 2004. The role of tourism in spreading dieback disease in Australian vegetation. In: Buckley, R. (Ed.), Environmental Impacts of Tourism. CAB International, New York, pp. 317–324.

Calais, S.S., Kirkpatrick, J.B., 1986. Impacts of trampling on natural ecosystems in the Cradle Mt – Lake St Clair National Park and implications for management. Australian Geographer 17, 6–15.

Campbell, J.E., Gibson, D.J., 2001. The effect of seeds of exotic species transported via horse dung on vegetation along trail corridors. Plant Ecology 157, 23–35.

Cater, C., Buckley, R., Hales, R., Newsome, D., Pickering, C., Smith, A., 2008. High Impact Activities in Parks: Best Management Practice and Future Research. Sustainable Tourism Cooperative Research Centre. Griffith University, Gold Coast.

Chiu, L., Kriwoken, L., 2003. Managing recreational mountain biking in Wellington Park, Tasmania, Australia. Annals of Leisure Research 6, 339–361.

Cole, D.N., 1983. Assessing and Monitoring Backcountry Trail Condition (Research Paper INT-303). USDA FS, Intermountain Forest and Range Experiment Station, Ogden.

Cole, D.N., 1987a. Research on soil and vegetation in wilderness: a state of knowledge review. In: Lucas, R.C. (Ed.), Proceedings of the National Wilderness Research Conference: Issues, State-of-Knowledge, Future Directions (Gen Tech Report INT-220). USDA FS, Intermountain Research Station, Ogden.

Cole, D.N., 1987b. Effects of three seasons of experimental trampling on five montane forest communities and a grassland in Western Montana, USA. Biological Conservation 40, 219–244.

Cole, D.N., 1991. Changes on Trails in the Selway-Bitterroot Wilderness, Montana, 1978–89 (Research Paper INT-212). USDA FS. Intermountain Research Station, Ogden.

Cole, D.N., 1995a. Experimental trampling of vegetation. I. Relationship between trampling intensity and vegetation response. Journal of Applied Ecology 32, 203–214.

Cole, D.N., 1995b. Experimental trampling of vegetation. II. Predictors of resistance and resilience. Journal of Applied Ecology 32, 215–224.

Cole, D.N. 2003. Ecological research and educational programs to support protected area management: lessons from the United States experience. In: Watson, A., Sproull, J. (Eds.), Science and Stewardship to Protect and Sustain Wilderness Values: Seventh World Wilderness CongressSymposium (Proceedings RMRS-P-27). USDA FS, Rocky Mountain Research Station, Ogden. pp. 213–217.

Cole, D.N., 2004a. Impacts of hiking and camping on soils and vegetation. In: Buckley, R. (Ed.), Environmental Impacts of Ecotourism. CABI Publishing, New York.
Cole, D.N., 2004b. Monitoring and management of recreation in protected areas: the contributions and limitations of science. In: Sievanen, T., Erkkonen, J., Jokimaki, J., Saarinen, J., Tuulentie, S., Virtanen, E. (Eds.), Proceedings of the Second International Conference on Monitoring and Management of Visitor Flows in Recreational and Protected Areas. Working Papers of the Finnish Forest Research Institute 2, pp. 9–16.
Cole, D.N., Bayfield, N.G., 1993. Recreational trampling of vegetation: standard experimental procedures. Biological Conservation 63, 209–215.
Cole, D.N., Monz, C.A., 2002. Trampling disturbance in high elevation vegetation, Wind River Mountains, Wyoming, U.S.A. Arctic, Antarctic and Alpine Research 34, 365–376.
Cole, D.N., Spildie, D.R., 1998. Hiker, horse and llama trampling effects on native vegetation in Montana, USA. Journal of Environmental Management 53, 61–71.
Conservation and Land Management [CALM], 2007. Mountain Bike Management Guidelines DRAFT, Department of Conservation and Land Management, Perth.
Cushman, J.H., Meentemeyer, R.K., 2008. Multi-scale patterns of human activity and the incidence of an exotic forest pathogen. Journal of Ecology 96, 766–776.
Cushman, J.H., Cooper, M., Meentemeyer, R.K., Benson, S., 2007. Human activity and the spread of *Phytophthora ramorum*. In: Proceedingsof the Sudden Oak Death Third Science Symposium. March 5–9, Santa Rosa, California (Gen. Tech. Rep. PSW-GTR-214). USDA FS, Pacific Southwest Research Station, Albany, pp. 179-180.
Daniel, R., Taylor, J., Guest, D., 2006. Distribution and occurrence of *Phytophthora cinnamomi* at Middle Head and North Head, Sydney Harbour. Australasian Plant Pathology 35, 569–571.
Davidson, J.M., Wickland, A.C., Patterson, H.A., Falk, K.R., Rizzo, D.M., 2005. Transmission of *Phytophthora ramorum* in mixed evergreen forest in California. Phytopathology 95, 587–596.
Davies, C., Newsome, D., 2009. Mountain Bike Activity in Natural Areas: Impacts, Assessment and Implications for Management. In: A Case Study from John Forrest National Park, Western Australia. Sustainable Tourism Cooperative Research Centre Report, Griffith University, Gold Coast.
Day, T.J., Turton, S.M., 2000. Ecological impacts of recreation along biking tracks and walking tracks. In: Bentrupperbäumer, J.M., Reser, J.P. (Eds.), Impacts of Visitation and Use: Psychosocial and biophysical windows on visitation and use in the Wet Tropics of Queensland World Heritage Area, Vol. 2. Wet Tropics Management Authority and Rainforest Cooperative Research Centre, James Cook University, Cairns, pp. 143–152.
Deluca, T.H., Patterson, W.A.I.V., Freimund, W.A., Cole, D.N., 1998. Influence of llamas, horses and hikers on soil erosion from established recreation trails in western Montana, USA. Environmental Management 22, 255–262.
Dieback Working Group [DWG], 2009. Managing *Phytophthora* Dieback in Bushland. Dieback Working Group, Perth.
Dixon, G., Hawes, M., McPherson, G., 2004. Monitoring and modelling walking track impacts in the Tasmanian Wilderness World Heritage Area, Australia. Journal of Environmental Management 71, 305–320.
Edwards, D.R., Moor, P.A., Workman, S.R., Bushee, E.L., 1999. Runoff of metals from alum-treated horse manure and municipal sludge. Journal of the American Water Resources Association 35, 155–165.
Environment Australia, 2001. Threat Abatement Plan for Dieback Caused by the Root-rot Fungus *Phytophthora cinnamomi*. Department of the Environment and Heritage, Australian Government, Canberra.
Felton, V., 2004. Trail Solutions: IMBA's Guide to Building Sweet Single Track. International Mountain Bicycling Association, Boulder.
Gillieson, D., Davies, J., Hardey, P., 1987. Gurragorambla Creek horse track monitoring in Kosciusko National Park, Unpublished report. Cited. 1993. In: Harris, J. (Ed.), Horse Riding Impacts in Victoria's Alpine National Park. Australian Ranger Autumn, pp. 3–17.
Goeft, U., Alder, J., 2001. Sustainable mountain biking: a case study from the southwest of Western Australia. Journal of Sustainable Tourism 9, 193–211.
Gower, S.T., 2008. Are horses responsible for introducing non-native plants along forest trails in the eastern United States? Forest Ecology and Management 256, 997–1003.
Pickering, C.M., Growcock, A.J. Impacts of experimental trampling on tall alpine herbfields and subalpine grasslands in the Australian Alps. Journal of Environmental Management, in press, doi:10.1016/j.jenvman.2009.09.022.
Hamblin, A., 2001. Land, Australia State of the Environment Report 2001 (Theme Report), CSIRO Publishing on behalf of the Department of the Environment and Heritage, Canberra.
Hammitt, W.E., Cole, D.N., 1998. Wildland Recreation: Ecology and Management, second ed. John Wiley and Sons, New York.
Hartley, E., 2000. Thirty-year monitoring of subalpine meadow vegetation following a 1967 trampling experiment at Logan Pass, Glacier National Park, Montana. In: Cole, D.N., McCool, S.F., Borrie, W.T., O'Loughlin, J., (Eds.), Proceedings: Wilderness Science in a Time of Change Conference Volume 5: Wilderness Ecosystems, Threats, and Management (Proceedings RMRS-P-15-VOL-5). USDA FS, Rocky Mountain Research Station, Ogden, pp. 124–132.
Higashino, P.K., Guyer, W., Stone, C.P., 1983. The Kilauea wilderness marathon and crater rim runs: sole searching experiences. Hawaiian Botanical Society 22, 25–28.
Hill, W., Pickering, C.M., 2006. Vegetation associated with different walking track types in the Kosciuszko alpine area. Journal of Environmental Management 78, 24–34.
Hill, R., Pickering, C.M., 2009a. Differences in the resistance of three subtropical vegetation types to experimental trampling. Journal of Environmental Management 90, 1305–1312.
Hill, W., Pickering, C., 2009b. Evaluation of Impacts and Methods for the Assessment of Walking Tracks in Protected Areas. Sustainable Tourism Cooperative Research Centre. Griffith University, Gold Coast.
Hill, W., Pickering, C., 2009c. Comparison of Condition Class, Track Problem Assessment and Point Sampling Methods in Assessing the Condition of Walking Tracks in New South Wales Protected Areas. Sustainable Tourism Cooperative Research Centre. Griffith University, Gold Coast.
Hobbs, R.J., Atkins, L., 1998. Effects of disturbance and nutrient addition on native and introduced annuals in plant communities in the Western Australian wheatbelt. Australian Journal of Ecology 13, 171–179.
Hockings, M., Twyford, K., 1997. Assessment and management of beach camping impacts within Fraser Island World Heritage Area, South-East Queensland. Australian Journal of Environmental Management 4, 26–39.
Jewell, M.C., Hammitt, W.E., 2000. Assessing soil erosion on trails: a comparison of techniques. In: Cole, D.N., McCool, S.F., Borrie, W.T., O'Loughlin, J., (Eds.), Proceedings: Wilderness Science in a Time of Change Conference Volume 5: Wilderness Ecosystems, Threats, and Management (Proceedings RMRS-P-15-VOL-5). USDA FS, Rocky Mountain Research Station, Ogden, pp. 133–140.
Johnston, F.M., Pickering, C.M., 2001. Alien plants in the Australian Alps. Mountain Research and Development 21, 284–291.
Jules, E.S., Kauffman, M.J., Ritts, W.D., Carroll, A.L., 2002. Spread of an invasive pathogen over a variable landscape: a nonnative root rot on Port Orford Cedar. Ecology 83, 3167–3181.
Landsberg, J., Logan, B., Shorthouse, D., 2001. Horse riding in urban conservation areas: reviewing scientific evidence to guide management. Ecological Management and Restoration 2, 36–46.
Leung, Y.-F., Marion, J.L., 1996. Trail degradation as influenced by environmental factors: a state-of-knowledge review. Journal of Soil and Water Conservation 51, 130–136.
Leung, Y.-F., Marion, J.L., 1999a. Assessing trail conditions in protected areas. Application of a problem assessment method in Great Smoky Mountains National Park. Environmental Conservation 26, 270–279.
Leung, Y.-F., Marion, J.L., 1999b. The influence of sampling interval on the accuracy of trail impact assessment. Landscape and Urban Planning 43, 167–171.
Leung, Y.-F., Marion, J.L., 2000. Recreation impacts and management in wilderness: a state of knowledge review. In: Cole, D.N., McCool, S.F., Borrie, W.T., O'Loughlin, J., (Eds.), Proceedings: Wilderness Science in a Time of Change Conference Volume 5: Wilderness Ecosystems, Threats, and Management (Proceedings RMRS-P-15-VOL-5). USDA FS, Rocky Mountain Research Station, Ogden, pp. 23–48.
Liddle, M.J., 1997. Recreation Ecology. Chapman and Hall, London.
Liddle, M.J., Thyer, N., 1986. Trampling and fire in a subtropical dry sclerophyll forest. Environmental Conservation 13, 33–99.
Lockwood, M., Worboys, G.L., Kothari, A., 2006. Managing Protected Areas: A Global Guide. Earthscan, London.
Mallen-Cooper, J. 1990. Exotic Plants in the High Altitude Environments of Kosciuszko National Park, South-eastern Australia PhD Thesis. Department of Biogeography and Geomorphology, Research School of Pacific Studies, Australian National University, Canberra.
Mallen-Cooper, J., Pickering, C.M., 2008. Linear decline in exotic and native species richness along an increasing altitudinal gradient in the Snowy Mountains, Australia. Austral Ecology 33, 684–690.
Marion, J.L., Leung, Y.-F., 2001. Trail resource impacts and an examination of alternative assessment techniques. Journal of Park and Recreation Administration 19, 17–37.
Marion, J.L., Olive, T., 2006. Assessing and Understanding Trail Degradation: Results from Big South Fork National River and Recreation Area. In: U.S. Department of the Interior. NPS Research/Resources Management. USGS Patuxent Wildlife Research Center, Virginia Tech Field Unit, Blacksburg.
Marion, J.L., Wimpey, J., 2007. Environmental impacts of mountain biking: science review and best practices. In: Webber, P. (Ed.), Managing Mountain Biking, IMBA's Guide to Providing Great Riding. International Mountain Bicycling Association (IMBA) Boulder, pp. 94–111.
Mastsui, A., Inoue, Y., Asai, Y., 2003. The effects of putting the bag with collecting faces and urea ("Equine Diaper") to the amount of ammonia gasses concentrated in Horse's pen. Journal of Equine Science 14, 75–79.
McDougall, K.L., Wright, G.T., 2004. Impacts of trampling in feldmark vegetation in Kosciusko National Park, Australia. Australian Journal of Botany 52, 315–320.
McKenzie, N., Jacquier, D., Isbell, R., Brown, K., 2004. Australian Soils and Landscapes. CSIRO Publishing, Melbourne, Australia.
Meinecke, E., 1928. A Report on the Effect of Excessive Tourist Travel on the California Redwood Parks. California State Printing Office, Sacramento.
Mende, P., Newsome, D., 2006. The assessment, monitoring and management of hiking trails: a case study from the Stirling Range National Park Western Australia. Conservation Science Western Australia 5, 285–295.
Monz, C.A., 2002. The response of two arctic tundra communities to trampling disturbance. Journal of Environmental Management 64, 207–217.
Monz, C.A., Pokorny, T., Freilich, J., Kehoe, S., Ayers-Baumeister, D., 2000. The consequences of trampling disturbance in two vegetation types at the Wyoming Nature Conservancy's Sweetwater River Project Area. In: Cole, D.N., McCool, S.F., Borrie W.T., O'Loughlin, J., (Eds.), Proceedings: Wilderness Science in a Time of Change Conference Vol. 5: Wilderness Ecosystems, Threats, and

Management (Proceedings RMRS-P-15-VOL-5). USDA FS, Rocky Mountain Research Station, Ogden, pp. 153–159.
Mouissie, A.M., Vos, P., Verhagen, H.M.C., Bakker, J.P., 2005. Endozoochory by free-ranging, large herbivores: ecological correlates and perspectives for restoration. Basic and Applied Ecology 6, 547–558.
Mount, A., Pickering, C.M., in press – on line in 2009. Testing the capacity of clothing to act as vector for non-native seed in protected areas. Journal of Environmental Management. doi.10.1016/j.jenvman.2009.08.002.
Naturebase, 2007. Creating the trail together. http://www.naturebase.net/content/view/431/895/ accessed 22nd October 2007.
Newsome, D., 2003. The role of an accidentally introduced fungus in degrading the health of the Stirling Range National Park ecosystem in south western Australia: status and prognosis. In: Rapport, D.J., Lasely, W.L., Roslton, D.E., Nielsen, N.O., Qualset, C.O., Damania, A.B. (Eds.), Managing for Healthy Ecosystems. Lewis Publishers, London, pp. 375–387.
Newsome, D., Davies, C., in press. 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.
Newsome, D., Phillips, N., Milewskii, A., Annear, R., 2002. Effects of horse riding on national parks and other natural ecosystems in Australia: implications for management. Journal of Ecotourism 1, 52–74.
Newsome, D., Cole, D., Marion, J., 2004. Environmental impacts associated with recreational horse riding. In: Buckley, R. (Ed.), The Environmental Impacts of Ecotourism. CAB International, New York, pp. 61–82.
Newsome, D., Smith, A., Moore, S.A., 2008. Horse riding in protected areas: a critical review and implications for research and management. Current Issues in Tourism 11, 1–23.
Olive, N.D., Marion, J.L., 2009. The influence of use-related, environmental, and managerial factors on soil loss from recreational trails. Journal of Environmental Management 90, 1483–1493.
Phillips, N., Newsome, D., 2002. Understanding the impacts of recreation in Australian protected areas: quantifying damage caused by horse-riding in D'Entrecasteaux National Park, Western Australia. Pacific Conservation Biology 7, 256–273.
Pickering, C.M., 2008. Literature Review of Horse Riding Impacts on Protected Areas and a Guide to the Development of an Assessment and Monitoring Program. Environment Protection Agency, Queensland Government, Brisbane.
Pickering, C.M., in press. Ten factors that affect the severity of visitor impacts in protected areas. Ambio 38.
Pickering, C.M., Hill, W., 2007a. Roadside weeds of the Snowy Mountains, Australia. Mountain Research and Development 27, 359–367.
Pickering, C.M., Hill, W., 2007b. Impacts of recreation and tourism on plant biodiversity and vegetation in protected areas in Australia. Journal of Environmental Management 85, 791–800.
Pickering, C.M., Mount, A., in press. Do tourists disperse weed seed? A global review of unintentional human-mediated terrestrial seed dispersal on clothing, vehicles and horses. Journal of Sustainable Tourism.
Potito, A.P., Beatty, S.W., 2005. Impacts of recreation trails on exotic and ruderal species distribution in grassland areas along the Colorado Front Range. Environmental Management 36, 230–236.
Quinn, D.L., Kolipinski, M., Coelho, V.R., Davis, B., Vianney, J.M., Batjargal, O., Alas, M., Ghoshi, S., 2008. Germination of invasive plant seeds after digestion by horses in California. Natural Areas Journal 28, 356–362.
Randall, M., Newsome, D., in press. Changes in the soil micro-topography of unplanned walking trails in South-western Australia. Conservation Science Western Australia.
Ross, P.M., 2006. Macrofaunal loss and microhabitat destruction: the impact of trampling in a temperate mangrove forest, NSW Australia. Wetlands Ecology and Management 4, 167–184.
Schaefers, J., 2006. Mountain biking. In: Buckley, R. (Ed.), Adventure Tourism. CAB International, New York, pp. 324–331.
Schahinger, R., Rudman, T., Wardlaw, T., 2003. Conservation of Tasmania Plant Species and Communities Threatened by Phytophthora cinnamomi: Strategic Regional Plan for Tasmania. Technical Report 03/03, Nature Conservation Branch, Department of Primary Industries, Water and Environment, Hobart.
Scott, J.J., Kirkpatrick, J.B., 1994. Effects of human trampling on sub-Antarctic vegetation of Macquarie Island. Polar Record 30, 207–220.
Shearer, B., Crane, C., Cochrane, A., 2004. Quantification of the susceptibility of the native flora of the southwest botanical province, Western Australia, to *Phytophthora cinnamomi*. Australian Journal of Botany 52, 435–443.
Specht, R.L., Specht, A., 1999. Australian Plant Communities: Dynamics of Structure, Growth and Biodiversity. Oxford University Press, Melbourne.
St John-Sweeting, R.S., Morris, K., 1991. Seed transmission through the digestive tract of a horse. In: Proceedings of the 9th Australian Weeds Conference. Adelaide, South Australia. Weed Management Society of Australia, pp. 170-172.
Summer, R.M., 1980. Impacts of horse traffic on trails in Rocky Mountain National Park. Journal of Soil and Water Conservation 35, 85–87.
Summer, R.M., 1986. Geomorphic impacts of horse traffic on montane landforms. Journal of Soil and Water Conservation 41, 126–128.
Sun, D., Liddle, M.J., 1993a. A survey of trampling effects on soils and vegetation in eight tropical and subtropical sites. Environmental Management 17, 497–510.
Sun, D., Liddle, M.J., 1993b. Plant morphological characteristics and resistance to experimental trampling. Environmental Management 17, 511–521.
Talbot, L.M., Turton, S.M., Graham, A.W., 2003. Trampling resistance of tropical rainforest soils and vegetation in the wet tropics of north east Australia. Journal of Environmental Management 69, 63–69.
Thomson, V.P., Leishman, M.R., 2004. Survival of native plants of Hawkesbury sandstone communities with additional nutrients: effects of plant age and habitat. Australian Journal of Botany 52, 141–147.
Thurston, E., Reader, R.J., 2001. Impacts of experimentally applied mountain biking and hiking on vegetation and soils of a deciduous forest. Environmental Management 27, 397–409.
Törn, A., Tolvanen, A., Narokorpi, Y., Tervo, R., Siikamäkei, P., 2009. Comparing the impacts of hiking, skiing and horse riding on trail and vegetation in different types of forest. Journal of Environmental Management 90, 1427–1434.
Turton, S.M., 2005. Managing environmental impacts of recreation and tourism in rainforests at the Wet Tropics of Queensland World Heritage Area. Geographical Research 43, 140–151.
Tyser, R.W., Worley, C.A., 1992. Alien flora in grasslands adjacent to road and trail corridors in Glacier National Park, Montana U.S.A. Conservation Biology 6, 253–262.
United States Department of the Interior [USDI], 2002. National Mountain Bicycling Strategic Action Plan. USDI Bureau of Land Management, Washington.
Wace, N., 1977. Australia – the isolated continent. In: Gibbs, A.J., Meischke, H.R.C. (Eds.), Pests and Parasites as Migrants: An Australian Perspective. Australian Academy of Sciences, Canberra, pp. 3–22.
Watson, A.E., Niccolucci, M.J., Williams, D.R., 1993. Hikers and Recreational Stock Users: Predicting and Managing Recreation Conflicts in Three Wildernesses (Research Paper INT-468). USDA FS, Intermountain Forest and Range Experiment Station, Ogden.
Weaver, V., Adams, R., 1996. Horses as Vectors in the Dispersal of Weeds into Native Vegetation. Proceedings of the 11th Australian Weeds Conference, 30 September 1996. School of Aquatic Sciences and Natural Resources, Melbourne, Victoria, pp. 383-397.
Weaver, T., Dale, D., 1978. Trampling effects of horses, hikers and bikes in meadows and forests. Journal of Applied Ecology 15, 451–457.
Weaver, T., Dale, D., Hartley, E., 1979. The relationship of trail condition to use, vegetation, user, slope, season and time. In: Proceedings: Recreational impact on wildlands, Seattle, WA, Oct. 27–29, 1978. USDA Forest Service, Pacific Northwest Region, R-6-001, pp. 94–100.
Webber, P. (Ed.), 2007. Managing Mounting Biking, IMBA's Guide to Providing Great Riding. International Mountain Bicycling Association, Boulder.
Wells, F.H., Lauenroth, W.K., 2007. The potential for horses to disperse alien plants along recreation trails. Rangeland Ecology and Management 60, 574–577.
Weste, G., Brown, K., Kennedy, J., Walshe, T., 2002. *Phytophthora cinnamomi* infestation – a 24 year study of vegetation change in forests and woodlands of the Grampians, Western Victoria. Australian Journal of Botany 50, 247–274.
Westendorf, M., 2009. Horses and Manure. Fact Sheet FS036. Rutgers University, New Brunswick.
Whinam, J., Chilcott, N., 1999. Impacts of trampling on alpine environments in central Tasmania. Journal of Environmental Management 57, 205–220.
Whinam, J., Chilcott, N., 2003. Impacts after four years of experimental trampling on alpine/subalpine environments in western Tasmania. Journal of Environmental Management 67, 205–220.
Whinam, J., Comfort, M., 1996. The impact of commercial horse riding on sub-alpine environments at Cradle Mountain, Tasmania, Australia. Journal of Environmental Management 47, 61–70.
Whinam, J., Cannell, E.J., Kirkpatrick, J.B., 1994. Studies on the potential impact of recreational horse riding on some alpine environments of the Central Plateau, Tasmania. Journal of Environmental Management 30, 103–117.
Whinam, J., Chilcott, N., Bergstrom, D.M., 2005. Subantarctic hitchhikers: expeditioners as vectors for the introduction of alien organisms. Biological Conservation 121, 207–219.
White, D.D., Waskey, M.T., Brodehl, G.P., Foti, P.E., 2006. A comparative study of impacts to mountain bike trails in five common regions of the southwestern U.S. Journal of Park and Recreation Administration 24, 21–41.
Willard, E.W., Cooper, D.J., Forbes, B.C., 2007. Natural regeneration of alpine tundra after human trampling: a 42 year data set from Rocky Mountain National Park, Colorado, U.S.A. Arctic. Antarctic and Alpine Research 39, 177–183.
Williams, J., Read, C., Norton, A., Dovers, S., Burgman, M., Proctor, W., Anderson, H., 2001. Biodiversity, Australian State of the Environment Report 2001 (Theme Report). CSIRO Publishing on behalf of the Department of the Environment and Heritage, Canberra.
Wilson, J.P., Seney, J.P., 1994. Erosional impacts of hikers, horses, motors cycles, and off-road bicycles on mountain trails in Montana. Mountain Research and Development 14, 77–88.
Worboys, S.J., Gadek, P.A., 2004. Rainforest Dieback; Risks Associated with Roads and Walking Tracks in the Wet Tropics World Heritage Area. Rainforest Cooperative Research Centre, Cairns.
Zabinski, C.A., Gannon, J.E., 1997. Effects of recreational impacts on soil microbial communities. Environmental Management 21, 1009–1432.
Zabinski, C., Wojtowicz, T., Cole, D., 2000. The effects of recreation disturbance on subalpine seed banks in the Rocky Mountains of Montana. Canadian Journal of Botany 78, 577–582.