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Review

Impacts of recreation and tourism on plant biodiversity and vegetation in protected areas in Australia

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Abstract

This paper reviews recent research into the impact of recreation and tourism in protected areas on plant biodiversity and vegetation communities in Australia. Despite the international significance of the Australian flora and increasing visitation to protected areas there has been limited research on recreational and tourism impacts in Australia. As overseas, there are obvious direct impacts of recreation and tourism such as clearing of vegetation for infrastructure or damage from trampling, horse riding, mountain biking and off road vehicles. As well, there are less obvious but potentially more severe indirect impacts. This includes self-propagating impacts associated with the spread of some weeds from trails and roads. It also includes the severe impact on native vegetation, including many rare and threatened plants, from spread of the root rot fungus *Phytopthora cinnamomi*. This review highlights the need for more recreational ecology research in Australia.

Keywords: Australia; Conservation; Plant biodiversity; Protected areas

Contents

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1. Introduction

Nature-based tourism and recreation, including in protected areas, is increasing worldwide and in Australia (Newsome et al., 2002a; Worboys et al., 2005). Overseas, a range of direct and indirect impacts of recreation activities in protected areas on vegetation have been documented in both observational and experimental studies (see recent reviews by Liddle, 1997; Leung and Marion, 2000; Newsome et al., 2002a; Buckley, 2004a, b; Cole, 2004; Newsome et al., 2004). Some impacts cause such damage that they alter the value of areas for tourism and recreation itself. In Australia, research into recreation ecology lags behind other regions, such as North America, despite there being equal need and it being of equivalent land area (Sun and Walsh, 1998; Buckley, 2005).

Damage to the Australian flora from recreation and tourism is important, as the flora is recognised internationally as important due to its high biodiversity, endemism, ancient origins and distinctive adaptations (Barlow, 1994; DEST, 1994; Williams et al., 2001). For example, Australia is recognised as one of the world's 17 mega diverse countries with ~23,000 native vascular plant species, ~85% of which are endemic (DEST, 1994). There are also 14 endemic plant families, including several representing early stages in the evolution of flowering plants (DEST, 1994; Williams et al., 2001).

Unfortunately, despite this recognition of the importance of the native flora, Australia currently has the fifth highest rate of land clearance in the world which is the highest of any developed nation with more than 564,800 ha of native vegetation cleared in 2000 (Williams et al., 2001). Land clearance since European settlement has resulted in the extinction of 61 plant species with an additional 1241 plant species vulnerable or threatened with extinction (DEH, 2005).

In part, to preserve important ecosystems and maintain populations of rare and threatened species, over 80,895,000 ha (over 10% of the Australian landmass) is currently conserved in over 7720 protected areas (CAPAD, 2004, Table 1). The importance of the flora in many of these protected areas is reflected in their international recognition, with many World Heritage Areas (Worboys et al., 2005). Recently, 15 Australian biodiversity hotspots have been recognised in areas that have many endemic species and are under immediate threat from human activities (DEH, 2003).

2. Recreation in protected areas in Australia

Nature-based recreation and tourism is popular in Australia, with large numbers of local and international tourists attracted by the numerous rich and diverse natural systems in national parks including World Heritage areas (Worboys et al., 2005). It is estimated that there are 84 million visits annually to protected areas in Australia, most of which is domestic tourism (Newsome et al., 2002a; Worboys et al., 2005). With this rise in tourism numbers there follows an inevitable increase in negative environmental impacts (Whinam and Chilcott, 2003; Liddle, 1997; Leung and Marion, 2000; Newsome et al., 2002a; Buckley, 2004a, b). In some cases impacts can even effect the quality of the tourism experience itself (Newsome et al., 2004).

Table 1
Extent of Australian terrestrial protected areas categorised by World Conservation Union (formerly International Union for the Conservation of Nature) IUCN protected area management categories (CAPAD, 2004)

IUCN category	Number	Area (ha)
IA	2090	18,212,695
IB	38	4,099,515
II	644	29,678,100
III	2019	970,517
IV	2060	2,818,936
Total	6851	55,779,762
V	139	919,746
VI	730	24,195,591
Total	869	25,115,337
Total	7720	80,895,099

Categories I–IV are reserved primarily for conservation.

Recreation and tourism activities in protected areas in Australia are usually restricted to those that have been considered to have less environmental impact and emphasise enjoyment of the natural values of the area (Buckley, 2004a; Worboys et al., 2005). Also, use of protected areas is often zoned, with some areas highly developed and extensively modified through provision of infrastructure such as sealed roads, carparks, toilets, visitor centres, picnic areas, camping areas and accommodation. These areas often attract large numbers of people. In contrast, other zones within the same protected areas may be classified remote (which can be designated as 'wilderness') where there is limited access, no or few facilities, and only small numbers of visitors, with restriction on the types of activities permitted (Worboys et al., 2005). For example, activities permitted under certain conditions in urban/developed zones of New South Wales national parks include snow sports (alpine skiing, snowboarding, cross-county skiing, ice climbing), camping in formal campsites, scenic driving, canoeing/kayaking/white water rafting, motorised boating, sailing/sail boarding, fishing, cycling, bushwalking on formal tracks, caving, organised mountain biking, powered and non-powered flight (Worboys et al., 2005). In contrast in remote/wilderness areas, activities are mainly limited to bushwalking on non-hardened trails, fishing, camping without facilities, and cross-country skiing.

3. Recreation and tourism impacts on vegetation in protected areas in Australia

Associated with increasing visitation to protected areas, there is increasing recognition of, and research into, the impacts from recreation and tourism. This paper provides a review of research on recreation and tourism impacts on vegetation in Australia with an emphasis on research published since Sun and Walsh's (1998) general review of environmental impacts of recreation and tourism in Australia. We concentrate on Australian research that is international significant, which examines impacts not previously described, or ecosystems for which there is limited existing research or that tests current models in recreation ecology theory.

3.1. Impacts associated with infrastructure for tourism and recreation

Recreation and tourism results in impacts in Australian protected areas, both from infrastructure and the activities themselves. The most obvious and direct impact is vegetation clearance in order to provide infrastructure. Although recreation and tourism infrastructure within protected areas is limited, there are often tracks, trails, roads, lookouts, fixed campsites and other types of accommodation provided, all of which have impacts (Table 2, Newsome et al., 2002a). In the construction of huts, lodges, hotels, roads, campgrounds and other facilities, native vegetation is cleared and replaced by either non-native vegetation or a built environment (Table 2, Spellerberg, 1998). However, damage is not just restricted to the initial removal of native vegetation. For example, the construction and use of roads and tracks can result in changes to hydrology and soils including erosion, sedimentation and pollutant runoff in adjacent areas (Table 2, Buckley and Pannell, 1990; Spellerberg, 1998; Newsome et al., 2002a). In addition roads and campsites can act as corridors/sites for the introduction and spread of pathogens and weeds (Table 2, Spellerberg, 1998; Newsome et al., 2002a; Buckley et al., 2004). Two of the classic studies examining the role of cars as vectors for weed seeds were conducted in Australia (Wace, 1977; Lonsdale and Lane, 1994).

A recent study comparing vegetation and soils on road verges and adjacent areas in the subalpine zone of Kosicuszko National Park in New South Wales (Johnston and Johnston, 2004) found that soils on the road verges had significantly lower levels of humus, more gravel and sand, lower levels of nutrients and lower pH and electrical conductivity than soils sampled 10 m away from the roads where there was native vegetation. In drainage areas just below the road, soils were also affected with significantly higher amounts of sediment, soil pH, and exchangeable levels of calcium and potassium than the roadside or natural areas. Vegetation composition and cover also differed, with roadsides having more bare ground (28%), and weed cover, than the nearby natural areas (2% bare ground, 6% weed cover). The drainage areas were dominated by one weed (*Achillea millefolium*—yarrow), which accounted for 91% of the ground cover (Johnston and Johnston, 2004).

Although the total area allocated to recreation and tourism infrastructure may be relatively small compared to the total area of a park, the impacts at that site are severe and often permanent (Smith and Newsome, 2002; Pickering and Buckley, 2003; Turton, 2005; Scherrer and Pickering, 2006). Also with linear disturbances such as those due to tracks and roads, the total area of disturbance may appear small, but due to the length of the road and verge effects and the area of impact on the verges, the actual footprint can be much larger (Spellerberg, 1998; Priskin, 2003; Donaldson and Bennet, 2004; Johnston and Johnston, 2004; Turton, 2005; Hill and Pickering, 2006). For example, a study on different track types in the alpine zone in Australia, demonstrated that the direct footprint on native vegetation (e.g. area of exotic plants or bare ground associated with the track) was 4290 m^2/km for wide gravel tracks (1 car width), 2940 m^2/km for narrow gravel tracks, and 2680 m^2/km for a track made from pavers (Hill and Pickering, 2006). However, a raised steel mesh walkway that was installed in the 1980s was not associated with either bare ground or a significant cover of exotics, indicating that careful selection of track type can dramatically reduce the direct environmental impact of such infrastructure on vegetation.

A common problem is that increasing recreation and tourism use of a site can often result in park managers

Table 2
Recent Australian research that has commented impacts on vegetation of recreation and tourism infrastructure

Impacts\type of activities	Campgrounds	Huts	Lodges, hotels, etc.	Roads	Tracks
Vegetation damage	1, 2, 3	4	4	5	6, 7, 8, 9, 11
Change in hydrology	2		4	5	8
Changes in soil conditions	1, 2, 3	4	4, 10	5	8, 9, 11
Spread of weeds	2, 3	4	4, 12	5, 12, 13,18,19	8,12
Spread of pathogens				5, 14, 15, 16, 17	15,16

References: (1) Turton et al. (2000a); (2) Smith and Newsome (2002); (3) Turton (2005); (4) Buckley et al. (2000); (5) Donaldson and Bennet (2004); (6) McDougall and Wright (2004); (7) Hill and Pickering (2006); (8) Johnston and Johnston (2004); (9) Turton et al. (2000b); (10) Walker (1991); (11) Day and Turton (2000); (12) Johnston and Pickering (2001); (13) McDougall (2001); (14) Weste (1998); (15) Worboys and Gadek (2004); (16) Newsome (2003); (17) Cowie and Werner (1993); (18) Bear et al. (in press); (19) Johnston et al. (in press).

hardening the site with a gradual change from natural to urban environment (Buckley and Pannell, 1990; Pickering and Buckley, 2003; Donaldson and Bennet, 2004; Worboys et al., 2005). Also, there can be changes in the expectations of visitors, with those participating in mass tourism in protected areas often requiring more sophisticated, hardened facilities than those engaging in backcountry activities. An alternative strategy is closure of some sites and/or education programs for visitors (Worboys et al., 2005). These approaches can be very successful as has been found on Fraser Island World Heritage area, where appropriate education has reduced the number of badly impacted camping sites even during peak usage periods (Hockings and Twyford, 1997).

3.2. Impacts associated with tourism activities

In addition to the impacts associated with infrastructure, there are impacts associated with recreation and tourism activities that do not require infrastructure, particularly those that occur in the backcountry. The most obvious impacts on vegetation from popular back country activities such as camping, horse riding, walking, off-road driving and mountain biking include vegetation being crushed, sheared off, and uprooted (Table 3, Liddle, 1997; Newsome et al., 2002a). These impacts result in changes to the vegetation including loss of height, biomass, reproductive structures (flowers, fruit, etc.), reduction in cover, increased litter, damage to seedlings and change in species composition (Table 3). Just as for tourism infrastructure, back country activities can also be associated with changes to the hydrology of the site, soil conditions including nutrients and erosion, as well as the introduction of weeds and pathogens (Table 3).

Direct impacts of recreation and tourism activities that are often less recognised/reported include root damage to trees by tethered horses or holes dug for human or other waste, trees cut for firewood and/or vandalism of vegetation at sites, and wildflowers and epiphytes harvested (Liddle, 1997; Newsome et al., 2002b; Phillips and Newsome, 2002; Smith and Newsome, 2002; Bridle and Kirkpatrick, 2003). For example, a common minimum impact guideline for camping and walking in backcountry areas is to dispose of human faeces and toilet paper by burying it small holes. However, when the impacts of digging these "cat-holes" was experimentally tested across a range of vegetation types in Tasmania it was found that digging holes damaged vegetation with lower overlapping cover after digging compared to before digging for a wide range of communities (Bridle and Kirkpatrick, 2003).

3.3. Factors that affect impacts from recreation and tourism

The extent of damage to vegetation from recreation and tourism will be influenced by factors such as the type of infrastructure provided, the amount of use of areas, the type of activity, the behaviour of tourists and the season of use (Liddle, 1997; Cole, 2004; Table 4). Some of the impacts of infrastructure have already been described in previous sections. When comparing different recreation activities it is commonly considered that cars tend to cause more damage that horse riding, which causes more damage than mountain bikes, which in turn cause more damage

Table 3
Recent Australian research that has documented impacts on vegetation from tourism and recreation activities

Impacts\type of activities	4WD	Horse-riding	Walking of tracks	Backcountry camping	Mountain-biking
Vegetation clearing/damage	1, 2	2, 3, 4, 5	2, 6, 7, 8, 9, 10	2, 8	2
Reduction in height		11, 12	10	10	
Reduced living biomass		4	7, 13, 16		
Reduced cover	1	3, 4, 11, 12	6, 7, 9, 10, 13, 15, 16	8	
Change in litter		3	9, 10	10	
Damage to seedlings				8	
Changes in species composition	2	11, 12	2, 10, 15	8	
Damage to trees (cutting, etc), eating			12	8, 10	
Reduction in surface profile		4	7, 8, 13		
Soil loss	1, 2	3, 11, 12	2		14
Soil compaction/change in soil moisture		11	9, 10	8, 10	14
Change in hydrology	1	5	2, 9	8	2
Spread of weeds	2	2, 4, 5, 11	2	2, 8	2
Spread of pathogens	2	2, 11	2	2	2

References: (1) Priskin (2002) (inferred from changes in number of tracks on aerial photos); (2) Turton (2005); (3) Whinam and Comfort (1996); (4) Whinam et al. (1994); (5) Landsberg et al. (2001); (6) Hill and Pickering (2006); (7) Whinam and Chilcott (1999); (8) Smith and Newsome (2002); (9) Talbot et al. (2003); (10) Growcock (2005); (11) Newsome et al. (2002b); (12) Phillips and Newsome (2002); (13) Whinam and Chilcott (2003); (14) Goeff and Alder (2001); (15) McDougall and Wright (2004); (16) Whiman et al. (2003).

Table 4
Recent Australian research into factors that affect the amount of damage from tourism and recreation activities

	Recent studies
Factor associated with activity	
Type of activity	Growcock (2005); Turton (2005).
Amount of use	Whinam et al. (1994); Goeft and Alder (2001); Landsberg et al. (2001); Newsome et al. (2002a, b); Phillips and Newsome (2002); Whinam and Chilcott (2003); Whinam et al. (2003); Talbot et al. (2003); Growcock (2005); Turton (2005).
Size of camping group	Smith and Newsome (2002); Growcock (2005).
Behaviour of user group	Newsome et al. (2002a,b); Smith and Newsome (2002); Turton et al. (2000b); Growcock (2005).
Factors associated with environment	
Resistances/resilience of vegetation	Whinam et al. (1994); Whinam and Comfort (1996); Turton et al. (2000b); Bridle and Kirkpatrick (2003); Talbot et al. (2003); Whinam and Chilcott (2003); Whinam et al. (2003); Growcock et al. (2004); McDougall and Wright (2004); Growcock (2005).
Topography site	Goeft and Alder (2001); Whinam and Chilcott (2003); Whinam et al. (2003).
Soil characteristics including drainage	Whinam et al. (1994); Whinam and Chilcott (1999); Arrowsmith and Inbakaran (2001); Talbot et al. (2003); Whinam et al. (2003); Growcock et al. (2004).
Climatic zone	Whinam et al. (1994); Bridle and Kirkpatrick (2003); Talbot et al. (2003); Whinam and Chilcott (2003); Whinam et al. (2003); Growcock (2005).
Seasonality	Buckley et al. (2004); DPIWE (2005); Turton (2005).

that walking (Liddle, 1997). This was found in recent Australian research in the Wet Tropics of Queensland World Heritage area, where trails used for mountain biking had higher levels of soil erosion and exposed rocks and tree roots than high-use walking trails (Day and Turton, 2000). Correspondingly, in studies comparing trampling and camping impacts in the Australian Alps, short stay camping (three nights) by small groups (four people) had limited impact on vegetation height and cover (although there were fire scars and axe damage to trees), while experimental trampling, particularly at high number of passes had a range of impacts on vegetation and recovery took longer (Growcock, 2005).

It is generally recognised that increased tourism use results in increased damage (Liddle, 1997; Newsome et al., 2002a; Cole, 2004; Newsome et al., 2004). This has been found in a wide range of experimental studies including in different vegetation types in Australia (Table 4). However, what is not clear is the form of the relationship with some studies indicating that the proportionally greatest damage occurs at low levels of use (Cole, 1995a, 2004), while other research has found that low levels of use may not cause damage in grassland communities (Growcock, 2005).

The size of a user party can also influence the area of damage with larger parties often causing a disproportionate amount of damage. For example, larger groups at campsites tend to cause more damage than smaller groups. In a study comparing impacts at high-use formal campsites and low-use informal campsites, in old growth eucalypt forest in a protected area in Western Australia, the high-use formal campsites were larger (mean size 876 m^2), had more tree damage, soil erosion, soil compaction, along with reduced vegetation cover and tree seedlings, greater degradation to riverbanks and more foot pads than the low-use informal campsites (177 m^2) (Smith and Newsome, 2002).

Behaviour can affect the intensity of impacts that may occur (Liddle, 1997; Cole, 2004, Table 4). Where user groups are aware of minimal impact behaviour, such as those in ‘leave no trace campaigns’, impacts may be reduced through careful consideration of campsite location, routes for hiking or riding, disposal of waste, etc. (Hercock, 1999; Cole, 2004; Growcock, 2005). Where such codes of behaviour are ignored or unknown, impacts can be more severe (Hercock, 1999; Growcock, 2005). For example the degree of impact from camping in the Wet Tropics in Queensland appeared to be associated with both the behaviour and type of user (Turton et al., 2000b). Low-use camping areas that were predominantly used by local residents had more litter, with more development of the site (fire rings, seating made from vegetation), more social trails, and more tree damage (including for firewood) compared to high-use camping areas where most visitors were not local.

Park managers have legislative requirements to manage recreation in ways that mitigate impacts and ensure that activities are ecologically sustainable. Recreation management includes prescribing the areas where particular activities are conducted and, less commonly limiting, visitor numbers or the size of groups. There appear to be few instances in Australia where either a maximum group size or a maximum number of groups/season are imposed (Hill and Pickering, 2002).

There are a range of environmental factors which can affect the amount of damage to vegetation by recreation and tourism activities. These include the characteristics of the vegetation, the topography of the site, soil characteristics, climatic zone and seasonality (Liddle, 1997; Cole, 2004, Table 4).

Studies in Australia along with those overseas have found that vegetation varies in its resistance and resilience to disturbance (Cole, 1995a, b; Liddle, 1997, Newsome et al., 2002a; Cole, 2004; Newsome et al., 2004, Table 4). Resistance is the relative ability of individual species to withstand disturbance before being damaged while resilience is the relative capacity of the vegetation to recover after disturbance (Liddle, 1997).

Aspects of plant morphology can affect resistance to damage, with some life-forms (low growing graminods, etc.) more resistant than others (shrubs, some forbs, etc. Cole, 1995b). As a result communities dominated by resistant life-forms will be damaged at higher use levels than sensitive communities dominated by life-forms such as shrubs (Cole, 1995a, b, Liddle, 1997; Whinam et al., 1994; Whinam and Chilcott, 2003; Growcock, 2005). Correspondingly plants vary in their resilience, resulting in some communities recovering faster from disturbance (Liddle, 1997). Generally there are three types of response: (1) species with high resistances, but are slow to recover once damaged; (2) species with low resistances but are relative fast to recover; and (3) species that have low resistance and low resilience and therefore are susceptible to damage from trampling and other types of visitor use (Liddle, 1997).

An example of how vegetation varies in resistance and resilience is seen from experimental trampling trials in the high country of Tasmania (Whinam and Chilcott, 1999; Whinam and Chilcott, 2003; Whinam et al., 2003). Trampling had a range of negative effects on the vegetation, with the degree of damage increasing with the number of passes by a walker. It also varied depending on the life form of the plants, with shrubs, tall tussock graminoids and cushion plants more susceptible to damage than lower growing graminoids (Whinam and Chilcott, 1999, Whinam and Chilcott, 2003; Whinam et al., 2003). The time taken for recovery also varied with intensity of use and life-form, with damage (changes in species richness, more bare ground, lower surface profile) still apparent in many communities 3–5 years after trampling (Whinam et al., 2003).

Differences in resistance and resilience to trampling can result in changes in species richness, with those taxa that are susceptible to damage lost from a community, while other taxa may increase in cover or even colonise disturbed areas. Trampling of the fragile feldmark vegetation along the ridges of the highest mountains in Australia resulted in a decrease in native species richness on tracks compared to adjacent vegetation, as well as a decline in the abundance of some species including the dominant prostrate shrub (McDougall and Wright, 2004). The shrubs in the feldmark have low resistance to trampling as the dominant shrub *Epacris microphylla* has brittle stems that are easily broken. Feldmark species are also characterised by exceptionally slow growth rates, and so will take decades to recovery from damage (McDougall and Wright, 2004).

Much of this and other trampling research has been conducted on low growing vegetation types (Cole, 2004). One of few studies worldwide examining trampling impacts in tropical forests found that species with broad thin leaves, year round growth, and occurring on moist friable soils that are easily compacted, had low resistance to trampling with reduction in vegetation cover occurring after as few as 25 passes (Talbot et al., 2003). Also in the Wet Tropics experimental day-use and camping trials reduced canopy cover and decreased cover of seedlings compared to controls with the extent of damage varying among forest types (rainforests, wet sclerophyll forest and littoral rainforest, Turton et al., 2000b).

Abiotic site characteristics such topography and hydrology will also affect the amount of damage from recreation and tourism activities (Table 4). Hiking, walking and bike riding on steep slopes causes greater damage than on flatter terrain (Goeft and Alder, 2001; Whinam and Chilcott, 2003). In Tasmanian alpine national parks, for example, experimental trampling on sloping buttongrass communities caused soil to become exposed and accumulate downslope after just 200 passes (Whinam and Chilcott, 2003). However, substrate type can offset the effect of slope. In a study of impacts of tracks in the Grampians National Park in Victoria, there was more damage to vegetation and soils along tracks at lower elevations where soils were deeper than at higher elevations where the tracks traversed rocky outcrops (Arrowsmith and Inbakaran, 2001).

Climatic zone also appears to affect the response of vegetation to recreational and tourism use (Table 4). For example, Australian research confirms overseas research that has found high-altitude vegetation communities are often more susceptible to damage than lower-altitude communities (Liddle, 1997; Table 4). Within a climatic zone, vegetation types can differ in their response to various intensities and types of impacts. In the Wet Tropics of Queensland, for example, rainforest, littoral forests and wet scherlophyll forests differed in the effect of day-use and camping on canopy cover, mineral soil exposure, soil compaction, vegetation cover and seedling density (Turton et al., 2000b). Wet sclerophyll forests were the most resistant, with rainforest intermediate and littoral forest the least resistant.

The resistance and resilience of vegetation can vary seasonally affecting the intensity of damage that may occur from a particular activity (Table 4). For example, the spread of pathogens such as the root rot fungus *Phytophthora cinnamomi* by mud on the boots of walkers and tires of vehicles varies with season, with wet periods resulting in a great risk of spread (Buckley et al., 2004; DPIWE, 2005). In the Wet Tropics of Queensland there were seasonal effects of tourism use with greater soil compaction, and lower seedling densities adjacent to walking tracks in the wet season compared to adjacent unused forest in the dry season (Turton, 2005).

3.4. Indirect impacts from tourism and recreation

Direct impacts from human activities may also be exacerbated by indirect impacts (Good, 1995; Buckley, 2003). Although there has been increasing recognition of the importance of indirect impacts of tourism on native vegetation in protected areas there has been far less research in this area (Buckley, 2003, 2005). Also, some indirect impacts can be self-sustaining: that is they can continue to occur even in the absence of further tourism use of the site (Buckley, 2003). Recent Australian research has highlighted self-sustaining indirect impacts including from increased nutrients and the introduction and spread of weeds and pathogens.

3.4.1. Addition of nutrients

Disposal of human waste (such as urine and faecal material) has direct effects such as removal of vegetation in order to dig a hole, but also has indirect effects through the addition of nutrients which can result in a change to species composition due to competitive displacement. This can create feedbacks for continuing change and also benefit weed species, leading to changes in vegetation communities. Research in Tasmania found a beneficial effect of low levels of nutrient addition (artificial urine) on vegetation, with increased growth of many taxa, with the only obvious negative effects on moss at one site (Bridle and Kirkpatrick, 2003).

Research on tourism impacts has highlighted how direct introduction of nutrients and/or re-suspension of sediments associated with swimming in dune lakes at Fraser Island in Queensland, affected algal growth, resulting in changes to ecosystem function (Hadwen and Bunn, 2004). This research also found that new methodologies may be required to detect these more subtle effects of recreation and tourism use.

3.4.2. Impacts of weeds

Another indirect and potentially self-sustaining impact of tourism is the accidental introduction of weed propagules on visitors' shoes, clothing and equipment. The risk associated with even low numbers of visitors to remote areas was recently highlighted in a study examining propagule load on people (in this case expeditioners) visiting a remote subantarctic island (Whinam et al., 2005). The study found 981 propagules on the clothing and equipment of just 64 people. High-risk items were equipment cases, daypacks and the cuffs and velcro closures on outer clothing. As a result there have been policy changes regarding clothing for people visiting subantarctic islands as part of expeditions from Australia.

Another important issue, in Australia and overseas, is the potential for exotics to spread from areas disturbed by tourism infrastructure into natural vegetation. In Australian protected areas, the verges of tracks and trails are often characterised by high diversity and cover of exotics, however, not all these species spread into undisturbed native vegetation and become important environmental weeds (Mallen-Cooper, 1990; Williams and West, 2000; Johnston and Pickering, 2001; Godfree et al., 2004; Johnston, 2005). Recent research in the Snowy Mountains in Australia has compared the ecological traits of species that spread compared with those that remain restricted to road and track verges (Godfree et al., 2004).

3.4.3. Impact of pathogens

Another important example of an indirect and self-sustaining impact of tourism is the spread of *P. cinnamomi* in protected areas in Australia. This root rot fungus is a threat to vegetation including many plants that are already classified as rare and threatened. This is discussed further in the following section.

4. Tourism impacts on rare and threatened plants

For rare and threatened plants the impacts of tourism are particularly severe as these species are already at risk of extinction. However, the impacts of tourism on rare flora including that in protected areas has not been generally recognised as a specific type of threat, even though there is evidence of negative environmental impacts from tourism on these taxa in protected areas (Kelly et al., 2003).

One clear example of tourism threatening rare and endangered plants is through the spread of the exotic soil-borne pathogen *P. cinnamomi* (Newsome, 2003; Schahinger et al., 2003; Buckley et al., 2004; DPIWE, 2005; Turton, 2005). This threat has been recognised nationally and it is listed as a key threatening process by the Australian Government (Environment Australia, 2001), and by the NSW government in the *Threatened Species Conservation Act 1995*. Tourism contributes to the spread of *P. cinnamomi* by transportation of spores in mud on footwear, tent pegs, trowels, horse hooves, bike tires and other types of vehicles. It is also spread during the construction and maintenance of tourism infrastructure (Newsome, 2003; Buckley et al., 2004; Donaldson and Bennet, 2004; Worboys and Gadek, 2004; DPIWE, 2005). Tourism can also contribute to the pathogen's impact by increasing the stress on plants within infected areas (Buckley et al., 2004).

In addition to the damage it causes to more common taxa, in Western Australia *P. cinnamomi* is a threat to at least 31 plant taxa already at risk of extinction with another 39 possibly susceptible, while in Tasmania, there are 39 plant taxa already at risk of extinction that are susceptible to infection (Barker and Wardlaw, 1995; Environment Australia, 2001; Schahinger et al., 2003; DPIWE, 2005). It is currently found in protected areas in Western Australia (e.g. up to 70% Stirling Range National Park) South Australia (Mount Lofty Ranges, Fleurieu Peninsula, Kangaroo Island), Victoria (Wilson's Promontory) and Tasmania (Southwest National Park, Freycinet National Park) (Newsome, 2003; Environment Australia, 2001; Newsome et al., 2002a; Schahinger et al., 2003;

Buckley et al., 2004; Worboys and Gadek, 2004; DPIWE, 2005; Turton, 2005).

Quarantine and hygiene are the main strategies that have been implemented by protected area managers to combat this threat. Some parks have permanent or seasonal closures of specific tracks, or sections within a park, or in a few cases whole parks are closed particularly in severely affected areas of Western Australia and South Australia (Newsome, 2003; Newsome et al., 2002a; Buckley et al., 2004). Hygiene procedures to minimise the spread of spores are implemented through education programs (signs, leaflets, etc.) which encourage/require visitors to wash down vehicles, boots, tent pegs, etc. when entering and leaving sites, and in some cases to visit uninfected sites before infected sites (Buckley et al., 2004; DPIWE, 2005).

5. Recommendations for future ecological research

In Australia, as overseas, much of the published research on recreation and tourism impacts on vegetation had quite a narrow focus concentrating on trampling and camping and horse riding (Sun and Walsh, 1998; Newsome et al., 2002a; Buckley, 2005, Table 3). There is limited research on the impacts of visitor infrastructure in protected areas, or into indirect impacts, including those that are self-sustaining (Buckley, 2002, 2003, 2005).

Based on the review here, consultation with protected area staff, discussions with researchers in recreational ecology, and the findings of Buckley's (2002) evaluation of ecotourism industry and protected area managers priorities a series of key areas for future ecological research are identified:

(1) Research into a range of visitor activities (camping, trampling, etc.) on Australian vegetation looking at levels of resistance and resilience. There are limited data for impacts of camping and trampling in rainforests, arid regions and deserts and swamp/bogs/fens in Australia and overseas. In Australia, there also needs to be more research into the impacts of mountain biking, rock-climbing and off-road driving which are increasing in popularity.

(2) Self-propagating, ecologically important indirect impacts of tourism and recreation such as the spread of weeds and pathogens.

Weeds have been identified as an important threat to the environment at all levels of government in Australia (Csuches and Edwards, 1998; Williams and West, 2000; Environment Australia, 2006). For protected areas it is important to determine how tourists may be introducing exotics and to identifying and characterising exotic plants that spread from tracks and trails into natural vegetation.

Correspondingly there is a need for more research into the dispersal of pathogens such as the fungus, *P. cinnamomi*, by visitors and vehicles. The severity of the threat from *P. cinnamomi* has been recognised nationally (Key Threatening Process, Environment Australia, 2001), by park agency staff and researchers (Schahinger et al., 2003). Although a range of studies have examined the fungus and its impacts more research is required into identifying susceptible species and to determine if vegetation eventually recovers.

(3) There is limited research into the impact of tourism infrastructure in Australia including comparisons of ecological costs/benefits of various types of tourism infrastructure.

6. Research needs for managing/monitoring of impacts

In addition to ecological research there is a need for further research into the best ways to monitor impacts and to manage impacts and tourists. This includes research into:

(1) Restoration ecology—how far and how fast impacted sites can recover if closed to visitors and how recovery can be accelerated. Rehabilitating sites damaged by infrastructure and visitor use is often expensive, ongoing and unfortunately, not always successful. Evaluating the success of different restoration methods remains a priority for many park agencies.

(2) Evaluating the impacts and benefits of different types of infrastructure once introduced through establishing monitoring programmes with ecologically appropriate indicators.

(3) Evaluating the success of specific management practices such those associated with limiting the spread of weeds and pathogens. For example, it is important to determine current quarantine practices are limiting the spread of root rot.

(4) Evaluating the extent and degree of 'impact creep', i.e. the gradual cumulative increase in impacts associated with increasing visitor numbers through incremental hardening of sites or displacement of activities from high-intensity tourism nodes into backcountry areas.

(5) Evaluate the success, cost and usefulness of current monitoring programs.

7. Conclusions

There are many threats to vegetation in Australian protected areas from tourism. Greater recognition needs to be given to this by protected area managers. Although the flora is internationally significant and protected area tourism is very popular there is still limited research on direct and indirect impacts of tourism for many Australian plant communities. Based on this review it is possible to identify future directions for research, and recommendations for current research.

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