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Research article

Comparing impacts between formal and informal recreational trails

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ABSTRACT

Globally there are hundreds of thousands of kilometres of recreational trails traversing natural areas of high conservation value: but what are their impacts and do impacts differ among trails? We compared the effects of four common types of recreational trails [(1) narrow and (2) medium width informal bare earth trails and (3) gravel and (4) tarmac/concrete formal trails] on vegetation adjacent to trails in a high conservation value plant community that is popular for mountain biking and hiking in Australia. Plant species composition was recorded in quadrats along the edge of the four types of trails and in control sites away from trails. Vegetation cover, the cover of individual growth forms, and species richness along the edges of all four types of trails were similar to the controls, although the wider trails affected plant composition, with the tarmac and gravel trails favouring different species. With very few comparative studies, more research is required to allow managers and researchers to directly compare differences in the severity and types of impacts on vegetation among trails. In the meantime, limiting damage to vegetation on the edge of hardened trails during construction, use and maintenance is important, and hardening trails may not always be appropriate.

1. Introduction

Nature based tourism and recreation is popular in many countries (Newsome et al., 2013), with over 8 billion visits to terrestrial protected areas globally (Balmford et al., 2015), and at least 84 million visits per year to national parks in Australia (Worboys et al., 2015). Some of the most popular activities are hiking and mountain biking, which take place on the hundreds of thousands of kilometres of recreational trails in protected areas (Liddle, 1997; Marion and Leung, 2001; Newsome et al., 2013; Ballantyne and Pickering, 2015a). These trails have a range of environmental impacts on flora, fauna, hydrology and soils (Liddle, 1997; Pickering and Hill, 2007; Newsome et al., 2013; Ballantyne and Pickering, 2015a).

Trails include those formally created and maintained by protected area agencies and other land managers (Marion and Leung, 2001, 2004; Godefroid and Koedam, 2004; Manning et al., 2005; Hill and Pickering, 2006; Nepal and Way, 2007; Ballantyne and Pickering, 2015a; Tomczyk et al., 2016), as well as informal trails created by users which are not designed, maintained or approved by land managers (Manning et al., 2005; Newsome and Davies, 2009; Monz et al., 2010a,b; Pickering et al., 2010a; Ballantyne and Pickering, 2015a). Although these trails may be superficially similar, they can differ in the types and severity of their impacts (Manning et al., 2005; Hill and Pickering, 2006; Ballantyne et al., 2014a; Ballantyne and Pickering, 2015a). Because of the lack of formal design considerations for informal trails, particularly when unhardened on steep slopes or mud areas, they can damage the soil surface resulting in soil erosion and compaction (Newsome and Davies, 2009; Barros et al., 2013; Ballantyne et al., 2014a). As informal trails tend to be poorly designed and unhardened, there can also be greater impacts from their use, including where people leave the main trail to avoid eroded or boggy areas, trampling vegetation on the trail edge and creating ribbon trails (Marion and Leung, 2001; 2004; Monz et al., 2010a,b; Barros et al., 2013).

Impacts from both formal and informal recreation trails include those from: (1) constructing trails, (2) the presence of the trail, (3) their use, (4) maintenance and (5) extreme climatic events (Marion and Leung, 2001; Nepal, 2003; Dixon et al., 2004; Godefroid and Koedam, 2004; Marion and Olive, 2006; Nepal and Way, 2007; Monz et al., 2010a,b; Tomczyk and Ewertowski, 2011; Ólafsdóttir and Runnström, 2013; Wolf and Croft, 2014; Tomczyk et al., 2016). The creation, maintenance and use of formal trails, whether unhardened or hardened, often involves clearing

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vegetation along the trail surface and sometimes along the verge (Dixon et al., 2004; Tomczyk and Ewertowski, 2011; Ólafsdóttir and Runnström, 2013; Barros et al., 2013). For some formal trails it also involves grading and hardening of the trail surface using materials such as gravel, rocks, bricks, tarmac or pavers (Leung and Marion, 2000; Godefroid and Koedam, 2004; Marion and Leung, 2004; Hill and Pickering, 2006; Wimpey and Marion, 2010) further altering vegetation along the edge of the trail. The presence of trails, particularly in forests where they create canopy gaps, have impacts in their own right, often resulting in more light, heat and wind along the trail corridor than in the undisturbed forest (Boucher et al., 1991; Godefroid and Koedam, 2004). The use of trails for different recreational activities such as hiking, mountain biking and horse riding adds to the impacts with trampling and other impacts along the trail surface, and in some cases, to vegetation along the trail edge (Deluca et al., 1998; Kutiel et al., 1999; Hamberg et al., 2008; Törn et al., 2009; Lucas-Borja et al., 2011; Barros et al., 2013). All of these impacts are of particular concern for trails traversing ecosystems and species already at risk of extinction, such as high conservation threatened plant species and communities (McDougall and Wright, 2004; Manning et al., 2005; Barros et al., 2013; Ólafsdóttir and Runnström, 2013; Ballantyne et al., 2014a; Ballantyne and Pickering, 2015a).

Changes in vegetation on and adjacent to trails are one of the most obvious impacts of trails (Leung and Marion, 1996; Godefroid and Koedam, 2004; McDougall and Wright, 2004; Nepal and Way, 2007; Barros et al., 2013; Wolf and Croft, 2014; Ballantyne and Pickering, 2015a; Ballantyne et al., 2016). On the trail edge there can be changes vegetation cover, plant height, abundance and composition along with the introduction and spread of weeds (Liddle, 1997; Marion and Leung, 2001; Godefroid and Koedam, 2004; McDougall and Wright, 2004; Hill and Pickering, 2006; Nepal and Way, 2007; Pickering et al., 2010b; Barros et al., 2013; Wolf and Croft, 2014; Ballantyne and Pickering, 2015a,c; Ballantyne et al., 2016). There have been numerous studies assessing changes to vegetation cover and height along the edge of trails, but fewer assessing changes in the presence/absence of individual species and their cover and hence the resulting changes in plant composition (Godefroid and Koedam, 2004; McDougall and Wright, 2004; Hill and Pickering, 2006; Nepal and Way, 2007; Barros et al., 2013; Ballantyne et al., 2014b; Ballantyne and Pickering, 2015a,c; Ballantyne et al., 2016).

There is even more limited research that has directly compared impacts among different types of trails including their impacts on soils and vegetation (Table 1). Of the seven studies addressing this issue identified in a recent systematic quantitative literature review (Ballantyne and Pickering, 2015a), along with an additional study published since the review (Ballantyne et al., 2016), only three directly compared impacts on plant composition among different types of trails within single plant communities (Godefroid and Koedam, 2004; Hill and Pickering, 2006; Ballantyne et al., 2016) (Table 1). This is despite the integral role that composition plays in maintaining ecosystem function and services and the resilience of plant communities.

The aim of the current study was to compare the types and severity of trail impacts on the edges of four different types of recreational trails in a plant community of high conservation value. This includes assessing if there are differences in vegetation cover, species richness and composition along the edges of the different trails and with control sites. The study was conducted in an endangered forest that is a popular destination for mountain biking and hiking. Previous research on trails in this type of forest found differences in the condition of the trail surfaces including soil loss and canopy gaps (Ballantyne et al., 2014a; Ballantyne and Pickering, 2015b), as well as some changes in the structure of the forest on the trail edges (Ballantyne and Pickering, 2015b), but did this equate to changes in the composition of the forest including the understory along trail edges?

2. Methods

2.1. Study location

Recreational trails are among the most common structures found in protected areas including in Australia. In south-eastern Queensland alone there are more than 2000 km of formal trails in national parks (Daly and Daly, 2009) and increasing numbers of informal trails including in high conservation value plant communities, such as the endangered Blackbutt forest (*Eucalyptus pilularis* regional ecosystem 12.11.23) (Pickering et al., 2010a; Ballantyne et al., 2014a; Ballantyne and 2015b). We assessed the impacts of four types of trails in this open-forest plant community that occurs on coastal metamorphics and interbedded volcanics (Queensland Government, 2014a). A total of 81% of this plant community has been lost over the last 150 years, with the remaining 1793 ha consisting of 226 separate remnants (Fig. 1) (Queensland Government, 2014a). Current threats to the plant community include clearing for agriculture and urban development, tourism and changing fire regimes (Queensland Government, 2014a).

The Blackbutt forest plant community occurs within the subtropical climate zone, with a mean annual maximum and minimum temperature of 25.1 °C and 14.4 °C, respectively, and an annual rainfall of 1251 mm (Bureau of Meterology, 2014). The plant community is found on coastal metamorphic rocks whose soils are not very fertile (Willmott, 2004). It is diverse with 140 plant species recorded, including 36 species of trees and shrubs and 15 weed species in the plant community, with an average of 44.7 species per forest remnant (Queensland Government, 2014a). Only one threatened plant species is known to occur in Blackbutt forest plant community: Native Jute (*Corchorus cunninghamii*) that is nationally listed as endangered (Australian Goverment, 2014b). However, the Blackbutt plant community supports endangered animals including the iconic Koala (*Phascolarctos cinereus*) which is nationally vulnerable (Australian Goverment, 2013) along with the regionally threatened Glossy Black Cockatoo (*Calyptorhynchus lathami*) and Green Thighed Frog (*Litoria brevipalmata*) (Queensland Government, 2014b).

Because many remnants of Blackbutt plant community occur in, or close to, urban areas, they are often popular sites for recreational activities such as hiking and mountain biking (Pickering et al., 2010a; Ballantyne et al., 2014a). Previous research on recreational trails in remnants of this plant community identified seven trail types based on the width, substrate and level of management (Ballantyne et al., 2014a; Ballantyne and Pickering, 2015b). The four most common are the focus of the current study (Fig. 2): (1) formal gravel trails (23% trails in forest), (2) formal tarmac/concrete trails (3.5%), (3) informal narrow bare earth trails (40%) and (4) informal medium bare earth trails (27%) of the 46.1 km of trails surveyed (Ballantyne et al., 2014b).

The impact of the trails on Blackbutt plant community was assessed in eight remnants of the plant community that fit the following criteria: (1) were greater than 5 ha, (2) were accessible to the public, and (3) contained examples of the four trail types (Ballantyne et al., 2014a). Across these remnants, 10 replicate sites for each trail type (40 sites in total) were randomly selected, along with 15 randomly located control sites. The control sites were located more than 50 m from the nearest trail or forest edge, showed no obvious evidence of human disturbance (rubbish, clearing, etc.) and so were more likely to represent 'natural' conditions in the plant community. All trail and control sites were

Table 1
Eight studies on the impact of different types of trails on plant communities. The studies were identified in a systematic search of peer-reviewed journals (Ballantyne and Pickering, 2015a) and a more recent paper (Ballantyne et al., 2016), with the results of two studies published in more than one paper (total 9 papers, but only from 8 studies). The impacts of trails have been categorised into negative (↓), positive (↑) and non-significant effects (0), while C indicates a significant change in composition. Superscripts next to the impacts represent the type of trails causing the difference. Y = Yes. * change in forest species richness (Farrell and Marion, 2002; Kim and Daigle, 2011, 2012).

Studies			Type of trails								Impacts of trails					
											On trail			Edge of trail		
Author	Nation	Climatic zone	1. Tarmac/Concrete	2. Pavers	3. Raised metal walkway	4. Gravel	5. Hardened	6. Sand	7. Formal unhardened	8. Informal unhardened	Vegetation cover	Soil loss	Soil compaction	Species richness	Species composition	Growth form composition
Farrell and Marion 2002	Chile	Sub-polar grassland				Y	Y			Y	↓ (8)	↓ (8)				
Godefroid and Koedam 2004	Belgium	Temperate deciduous oak and beach forest	Y	Y		Y		Y	Y				↓ (1,2,4)	↑ (2,4)*	C (1,2,4,7)	C (1,2,4,6,7)
Manning et al. 2005	USA	Humid maritime modified woodland				Y	Y			Y	↓ (8)	↓ (5,8)	↓ (8)			
Hill and Pickering 2006	AUS	Alpine herbfield		Y	Y	Y				Y	↓ (2,4,8)			↓ (2,4)	C (2,4,8)	C (2,4,8)
Monz et al. 2010	USA	Subalpine shrub	Y				Y			Y	↓ (8)	↓ (8)				
Kim and Daigle 2010, 2012	USA	Subalpine shrub	Y							Y	0					
Ballantyne et al. 2014a, Ballantyne and Pickering 2015b	AUS	Subtopic tall open forest	Y			Y				Y	↓ (1,4,8)	↓ (1,4,8)	0			
Ballantyne et al. 2016	AUS	Temperate woodland	Y			Y			Y	Y	↓ (1,4,7,8)	↓ (8)	0	↓ (1,7)	C (1,4)	C (1,4,7,8)

located in areas that had not been burnt within the previous 10 years to minimise differences among sites in early forest regeneration post fire. Vegetation was sampled in a total of 55 sites (4 trail types × 10 replicates for each trail type plus 15 control sites).

All sites had similar soil type, topography, slope, altitude, aspect and canopy cover (Ballantyne and Pickering, 2015b) reflecting the relative uniformity in many abiotic characteristics within the Blackbutt plant community. There were differences in the impacts on the surface of the trail, with less soil loss from narrow bare earth trails compared to the others (Ballantyne and Pickering, 2015b). There were canopy gaps above the trails with less vegetation cover in the canopy for all trails compared to natural forest, except the narrow bare trails (Ballantyne and Pickering, 2015b).

For the 40 trail sites, a 2 m wide by 20 m long quadrat was laid out parallel and touching the edge of one side of the trail, with the side randomly selected. Because of differences in potential impacts on understorey and canopy vegetation the two strata were recorded separately. To sample the understorey, 120 points were systemically randomly located within the quadrat. A rod 0.5 cm wide and 150 cm long was then placed vertically down at that point, and all plant species touching the rod recorded. To sample the canopy, at each of the same 120 points, a laser pointer was shone vertically up from the top of the rod and any plant species touched by the laser recorded. In addition to recording any species touched at each point, the presence or absence of vegetation, litter or bare ground (understorey) and vegetation and sky (canopy) was also recorded for each point (a single value per point). Plant species within a quadrat but not 'hit' by one of the 120 points were recorded and given a default cover area of the lowest value, i.e. 0.71%. Species classification was based on the electronic form of the New South Wales Flora (PlantNET, 2011). Each plant species was also categorised based on its growth form (tree, shrub, fern, liana, herb, sedge or grass).

From the point data, absolute cover values for vegetation and overlapping cover values for individual species were calculated per quadrat. Overlapping cover values for individual species were calculated by dividing the total number of hits per quadrat for a species by the total 120 points per quadrat and multiplying by 100 to give a percentage cover value per species for the quadrat. The total number of hits for vegetation, litter and bare ground were divided by 120 and then multiplied by 100 to give an absolute value for each of these variables.

2.2. Statistical analysis

To compare differences in composition and growth form among the four trail types and controls in the understorey and canopy, Bray-Curtis dissimilarity matrixes were calculated in the ordination package, Primer (version 6). This was done separately for the overlapping cover of (1) understory species, (2) canopy species, (3) understorey growth forms, and (4) canopy growth forms giving four ordinations. The ordinations for species cover were square root transformed to deal with large numbers of species with low cover values. The cover of growth forms was calculated by summing the percentage cover data for all species with that growth form. Using the Bray-Curtis dissimilarity matrices, non-metric multidimensional scaling (NMDS) plots were generated. These types of ordinations are a commonly used method for comparing ecological composition data (McCune and Grace, 2002). They visually represent differences in species composition or growth form

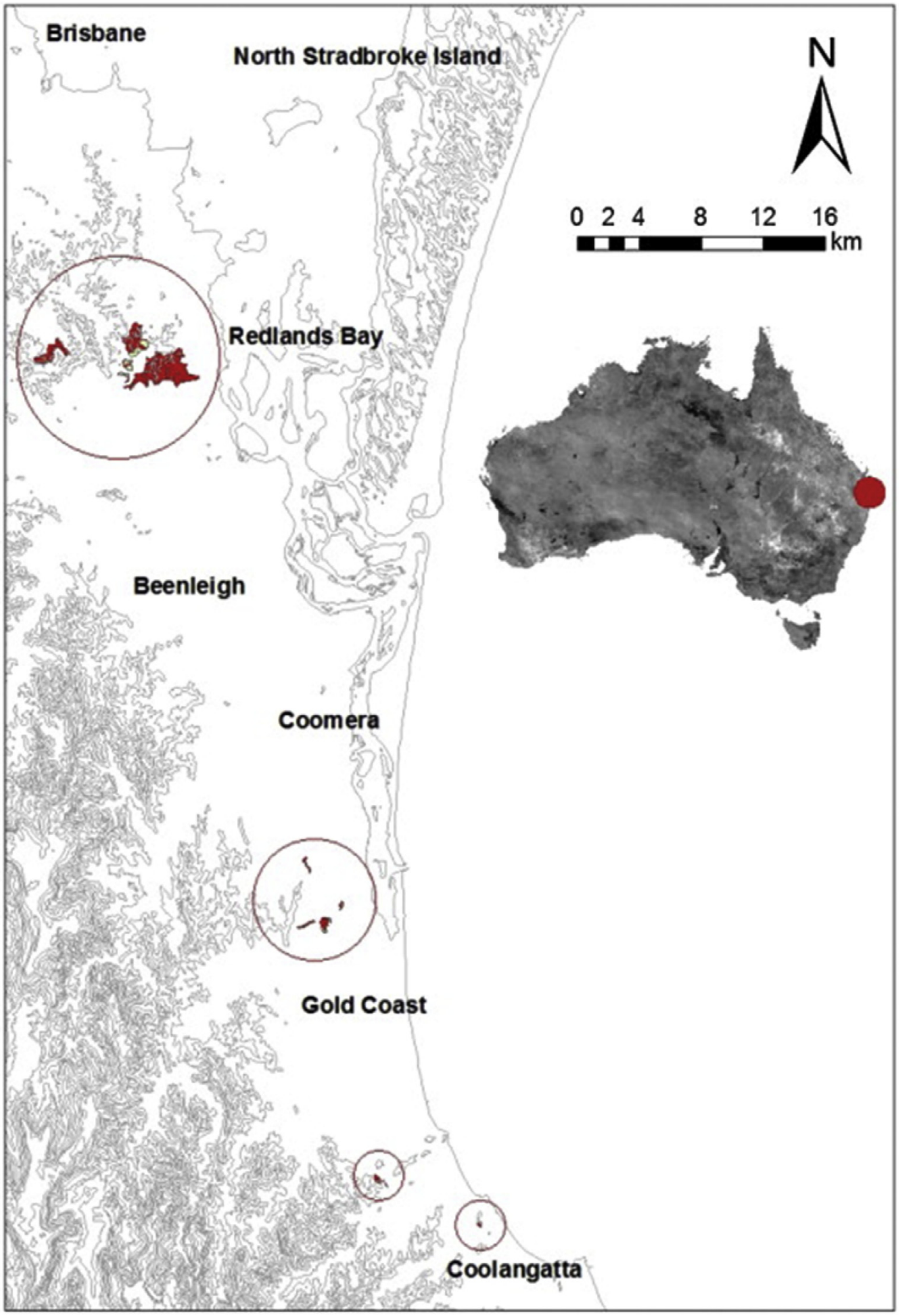

Fig. 1. Location of remnants of Blackbutt forest plant community (red) surveyed and their general location within Australia (Ballantyne et al., 2014a). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

composition among the four trail types and controls in two dimensions. Analysis of similarity (ANOSIM) were then used to quantitatively compare differences in species composition and growth forms for the understorey and for the canopy (Clarke, 1993). The SIMPER function was used on the NMDS matrices to establish which individual species or growth forms contributed to differences among trail types and controls.

To assess differences in vegetation among the trail edges for the single dependent variables; species richness, absolute vegetation cover, and the overlapping cover of each of the 10 most common species (e.g. occurred in more than half the quadrats), a series of Linear Mixed Models were performed separately for data for the understorey and the canopy, with the four trail types and controls as a fixed variable (treatment), site as a fixed variable and remnant as a random variable, using SPSS version 20 (IBM, 2011). To meet the assumptions of the tests for overlapping cover data (percentage cover), the dependent variables were logit transformed prior to analysis.

Fig. 2. The four trail types assessed (a) tarmac/concrete (2–4 m wide) and (b) gravel (2–4 m wide) formal trails, and (c) narrow (<2 m wide), and (d) medium width (2–4 m wide) informal bare earth trails.

3. Results

The Blackbutt plant community has high species diversity with over 134 species recorded in the 55 quadrats, 129 in the understory and 37 in the canopy, 19 of which were weeds (e.g. not native to Australia). Of the plant species recorded, only 10 species were relatively common, occurring in more than 50% of the quadrats, reflecting variability in species composition within quadrats in the Blackbutt plant community.

3.1. Trail effects on species composition

Hardened trails affected species composition in the understory (Table 2, Fig. 3a). Species composition adjacent to the gravel and tarmac trails was significantly different to controls in the understory, but there were no significant differences between the medium and narrow bare earth informal trails and controls in the understory (Table 2). The tarmac trails appeared to have the greatest effect on plant composition with differences in trail edge vegetation between it and the controls (79% dissimilarity), the narrow bare earth (77%) and the medium gravel trails (82%) in the understory (Table 2, Fig. 3a). The differences with the controls were driven by changes in the cover of a range of native species in the understory. Adjacent to the tarmac trails there was more *Imperata cylindrica* and *Lomandra longifolia,* but less *Entolasia stricta*, *Ottochloa gracillima, Lomandra multiflora, Lepidosperma laterale, Themeda triandra* and the fern *Pteridium esculentum* compared to controls (Table 3) although these differences were not apparent when the cover of the species were individually compared with the controls (Table 4).

The composition of the understorey adjacent to gravel trails also differed to controls with an average 78% dissimilarity overall (Tables 2 and 3). This was due in part to a higher cover of the grasstree *Xanthorrhoea latifolia* and the grass *Alloteropsis semialata*, but a decrease in the cover of other grasses, including *I. cylindrica, Entolasia stricta, L. laterale, O. gracillima* and *T. triandra* on the edge of gravel trails compared to controls (Table 3). The only individual species to show a significant affect between the controls and trails, was *Lomandra multiflora,* where it had a higher cover in the control quadrats than on those on the edge of the gravel trail ($P = 0.003$ between gravel and controls) (Tables 3 and 4).

In contrast to the understory, there were limited differences in canopy species composition between trails and the controls (Table 2, Fig. 3b), with the only significant difference in the canopy between the medium bare earth trail compared to controls (Tables 2 and 3). There was more *Allocasuarina littoralis* and *Eucalyptus racemose*, but slightly less cover of *Eucalyptus pilularis* in the canopy by the medium bare earth trail compared to the controls based on SIMPER results, but these differences were not apparent when compared for the species individually (Tables 3 and 4).

3.2. Trail effects on growth forms

Although there were no significant differences for the growth forms separately between the trails and controls using linear mixed models (Table 4), there were differences in the combined effect of growth forms analysed using ANOSIM's (Table 2). The two hardened trails were significantly different to controls in the understory, potentially due to the combined effects of reduced cover of grasses and sedges adjacent to hardened trails compared to controls

Table 2
Results from ANOSIMs comparing species composition (square root transformation) and growth forms among the four trail types and the control quadrats including pair-wise post hoc tests. Significant P values are in bold.

	Control	Narrow bare earth	Medium gravel	Medium bare earth	Medium tarmac
Understorey composition, P = **0.005**					
Control					
Narrow bare earth	0.580				
Medium gravel	**0.026**	0.351			
Medium bare earth	0.134	0.684	0.183		
Medium tarmac	**0.001**	**0.010**	**0.001**	0.107	
Canopy composition, P = **0.024**					
Control					
Narrow bare earth	0.185				
Medium gravel	0.250	0.306			
Medium bare earth	**0.043**	0.646	0.330		
Medium tarmac	0.152	0.472	0.083	**0.040**	
Understorey growth forms, P = **0.010**					
Control					
Narrow bare earth	0.096				
Medium gravel	**0.016**	0.206			
Medium bare earth	0.167	0.330	0.110		
Medium tarmac	**0.019**	0.159	0.317	0.262	
Canopy growth forms, P = **0.042**					
Control					
Narrow bare earth	0.461				
Medium gravel	**0.042**	0.215			
Medium bare earth	**0.037**	0.288	0.798		
Medium tarmac	**0.015**	0.160	0.340	0.352	

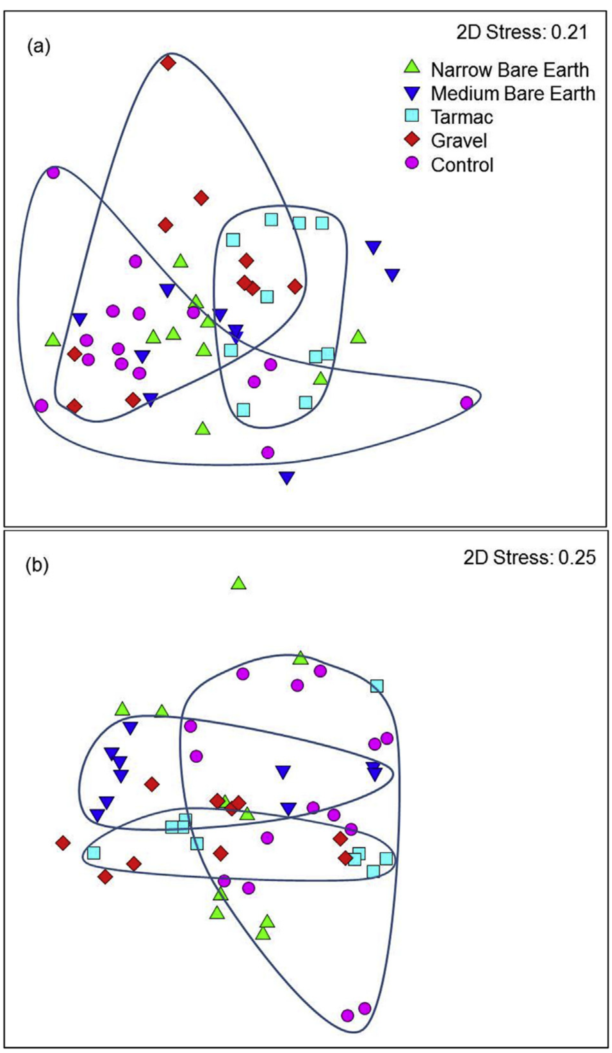

Fig. 3. Ordinations of overlapping cover of species (square root transformed) within the understory (a) and canopy (b). Trail types that were significantly different from controls are highlighted with circles.

(Table 5). There was a trend in fern cover, with no ferns next to tarmac trails, some ferns next to other trails, and 7.9% fern cover in controls, but this was not significant (Tables 4 and 5). There was also no significant differences in the cover of weeds in the understory among trails, in part due to the very low cover of weeds within quadrats and the large number of quadrats without any weeds (Tables 4 and 5). In the canopy, all three medium width trails differed to the controls (Table 2) with the two hardened trails associated with less tree cover, whereas the informal medium bare earth trail had increased cover of vines compared to controls (Tables 4 and 5).

3.3. Effects on vegetation cover, richness and weeds

Despite the differences in composition and growth forms among trails, there were no effects on overall vegetation cover in the understorey ($P = 0.250$), or the canopy ($P = 0.142$) (Tables 4 and 5). The average vegetation cover (±SE) for all trails and control quadrats was 62.5% ± 20.3 for the understorey and 84.1% ± 12.0 for the canopy.

The average number of species per quadrat also did not significantly differ among trails or with the controls for the canopy ($P = 0.250$), with an average of 5.3 ± 1.5 species in the canopy (Tables 4 and 5). However, there was a non-significant trend in species richness in the understory ($P = 0.055$) (Table 4), with slightly fewer species by the tarmac and gravel trails compared to the controls (Table 5).

4. Discussion

Nature based tourism is a common activity in many areas of high conservation value, though it can come at a cost to those environments. This study assessed which trail types had the greatest influence on plants growing along the trail edges. The results show that the two formal trails, gravel, and in particular tarmac, have the greatest impact on plants on the edge of the trails.

4.1. Trails affected plant composition

Overall, there were relatively few impacts on species composition adjacent to trails compared to other studies comparing

Table 3
Results for understory and canopy vegetation showing differences in cover of the most important species contributing to the separation of those trail types that were significantly different to controls in the ANOSIM's using the from SIMPER function in Primer.

Species	Cover		Dissimilarity		%
	Average		Average	SD	Cumulative
79.17%	Tarmac	Control			
Imperata cylindrica	17.0	14.4	10.3	1.2	13.1
Entolasia stricta	8.2	13.1	7.5	1.1	22.5
Ottochloa gracillima	0.4	9.1	4.9	0.8	28.7
Lomandra multiflora	5.9	8.4	4.6	1.4	34.5
Lepidosperma laterale	0.5	9.4	4.6	0.8	40.3
Lomandra longifolia	7.5	0.5	4.0	0.7	45.3
Themeda triandra	3.1	6.1	3.7	1.0	50.0
Pteridium esculentum	0.1	5.9	3.3	0.5	54.2
78.13%	Gravel	Control			
Xanthorrhoea latifolia	19.9	2.7	10.1	0.6	12.9
Imperata cylindrica	2.9	14.4	7.4	0.8	22.4
Entolasia stricta	8.7	13.1	6.6	1.1	30.8
Lepidosperma laterale	7.1	9.4	5.6	0.9	37.7
Ottochloa gracillima	3.2	9.1	4.7	0.8	43.7
Alloteropsis semialata	7.1	5.7	4.3	1.1	49.2
Themeda triandra	4.6	6.1	3.8	1.0	54.1
Lomandra multiflora	3.9	8.4	3.5	1.4	58.0
78.9%	Medium Bare Earth	Control			
Eucalyptus pilularis	33.7	36.2	16.8	1.2	21.2
Allocasuarina littoralis	41.4	11.5	15.7	1.1	41.1
Eucalyptus racemosa	29.2	10.5	12.3	0.9	56.7

Table 4
Results from linear mixed models comparing species richness, cover of growth forms and the 10 most common species in the canopy and understorey (e.g. occurred in more than 50% of quadrats) among the four trail types and with the control. Significant P values are in bold.

Variables	Understorey	Canopy
	P-value	P-value
Total species richness	0.055	0.250
Vegetation cover	0.250	0.142
Fern	0.112	–
Grass	0.462	–
Herb	0.063	–
Sedge	0.174	–
Shrub	0.943	–
Tree	0.471	0.543
Vine	0.422	–
Weed	0.249	–
Allocasuarina littoralis	0.273	0.106
Cymbopogon refractus	0.615	–
Entolasia stricta	0.900	–
Eucalyptus pilularis	–	0.722
Goodenia rotundifolia	0.057	–
Imperata cylindrica	0.126	–
Lepidosperma laterale	0.098	–
Lomandra multiflora	**0.027**	–
Ottochloa gracillima	0.129	–
Themeda triandra	0.101	–

different trail types. This is despite the severity of impacts previously documented on the surface of the same trails as well as the effects of the trail on the structure of the adjacent forest. Previous research on Blackbutt forest found a range of impacts along the trail itself, as well as adjacent to the trail, including reductions in tree density, and increases in sapling abundance (Pickering et al., 2010a; Ballantyne et al., 2014a; Ballantyne and Pickering, 2015b). Along the trail surface itself, impacts included soil erosion and compaction, as well as reduced canopy cover above the trails (Pickering et al., 2010a; Ballantyne et al., 2014a; Ballantyne and Pickering, 2015b). Although we found there were also changes in composition and some effects on growth forms along the edges of the hardened trails, there were no effects on species richness, total vegetation cover, the cover of most growth forms and weeds when assessed separately.

Differences in composition, but not in vegetation cover suggests that trails favoured a slightly different suite of species better adapted to living in more open and disturbed conditions on compacted soils close to the trail whilst maintaining similar levels of diversity and cover. In the Blackbutt forest it seems that differences in composition were driven by changes in the cover of a few native sedge and grass species adjacent to the two hardened trails, with declines in some of the more common but trampling sensitive native species including prostrate slender grasses and taller tussock grasses and sedges. Vegetation adjacent to trails is often dominated by ruderal species that have the ability to grow in areas too disturbed for other species (Godefroid and Koedam, 2004; Potito and Beatty, 2005; Nepal and Way, 2007; Barros et al., 2013; Ballantyne et al., 2016). Although ruderal species adjacent to trails often include weeds (Hill and Pickering, 2006; Ballantyne et al., 2016), this was not the case in the Blackbutt forest, where there were differences in native species, but weeds were uncommon and had low cover. There was also a trend for higher coverage of some tree species by the bare earth trail in the Blackbutt forest, possible resulting in their growing into canopy gaps created by the loss of other trees along the trail surface. In contrast, vegetation along the narrow bare earth trail was similar to that in control quadrats with no significant differences to controls in the understory or canopy vegetation.

The three other studies comparing differences among trail types on vegetation, also found that vegetation on the edge of wider and/or hardened trails differed from controls (Godefroid and Koedam, 2004; Hill and Pickering, 2006; Ballantyne et al., 2016), but the severity of some impacts were greater in other plant communities including for hardened trails with weed verges. For instance, the vegetation on the edge of medium gravel and unhardened trails and a wide tarmac trail differed in richness and/or composition to controls in a *Eucalyptus* grassy woodland in South Australia

Table 5
Differences in the number of species, percent vegetation cover, average number of species per quadrat, frequency (number of quadrats) and cover of growth forms in the understorey and canopy adjacent to the four trail types and in the controls. Mean and Standard Error (SE) are for overlapping cover values. N = 10 for each trail type and N = 15 for the control quadrats.

	Total		Narrow bare earth		Medium bare earth		Tarmac		Gravel		Control	
	Freq.	Mean ± SE	Freq.	Mean ± SE	Freq.	Mean ± SE	Freq.	Mean ± SE	Freq.	Mean ± SE	Freq.	Mean ± SE
Understory												
Species total		129		60		79		51		54		81
% Veg. cover		64.8 ± 2.6		62.6 ± 4.6		63.6 ± 6.4		55.0 ± 4.6		62.6 ± 9.3		75.1 ± 3.5
Species per quadrat		17.1 ± 0.6		16.6 ± 1.1		18.6 ± 1.4		15.1 ± 1.2		15.5 ± 1.7		18.7 ± 1.3
Fern	12	2.8 ± 1.3	2	1.4 ± 1.1	2	0.5 ± 0.4			1	1.5 ± 1.1	7	7.9 ± 4.6
Grass	55	50.7 ± 3.7	10	48.7 ± 5.2	10	40.9 ± 7.7	10	36.5 ± 6.6	10	57.7 ± 10.9	15	63.3 ± 7.4
Herb	39	2.5 ± 0.4	6	1.4 ± 0.5	8	3.1 ± 1.1	9	2.8 ± 0.7	5	1.8 ± 0.8	11	2.9 ± 1.2
Sedge	48	19.8 ± 2.5	8	19.3 ± 7.2	10	23.2 ± 6.0	8	14.6 ± 4	9	13.7 ± 5.5	13	25.5 ± 4.9
Shrub	38	3.7 ± 0.8	8	3.6 ± 1.4	7	4.4 ± 1.6	7	5.1 ± 3.5	7	2.7 ± 1.0	9	3.1 ± 1.4
Tree	53	8.8 ± 0.9	9	12.6 ± 3.1	10	9.3 ± 1.5	9	4.9 ± 0.9	10	7.3 ± 1.4	15	9.5 ± 2.0
Vine	24	1.6 ± 0.4	3	1.3 ± 0.9	7	2.1 ± 0.9	5	1.5 ± 0.6	4	0.9 ± 0.4	5	1.93 ± 1.3
Weeds	27	1.7 ± 0.4	4	3.1 ± 1.9	9	3.1 ± 1.3	5	2.2 ± 0.2	4	0.4 ± 0.2	5	0.4 ± 0.2
Canopy												
Species total		37		19		18		18		16		24
% Veg. cover		84.1 ± 1.6		87.3 ± 3.7		82.4 ± 4.0		75.0 ± 5.1		82.5 ± 2.6		90.3 ± 1.7
Species per quadrat		5.0 ± 0.2		5.0 ± 0.4		4.8 ± 0.5		4.9 ± 0.3		4.6 ± 0.5		5.7 ± 0.4
Shrubs	8	2.1 ± 1	3	4.0 ± 2.6	2	0.5 ± 0.3	1	4.2 ± 4.2	2	2.9 ± 2.3		
Trees	55	110.1 ± 1.6	10	108.5 ± 4.5	10	112.7 ± 3.5	10	100.9 ± 6.3	10	108.8 ± 4.2	15	116.5 ± 3.5
Vines	8	1.6 ± 0.7			3	4.9 ± 2.8			1	2.6 ± 2.6	4	0.6 ± 0.4
Weeds	2	0.4 ± 0.3	1	1.7 ± 1.7	1	0.3 ± 0.3		0		0		0

Freq = Frequency, SE = Standard error of the mean, Veg. cover = Vegetation cover.

(Ballantyne et al., 2016) with more weeds but fewer native bulbs closer to the trails. Again, there were few differences in vegetation adjacent to narrow unhardened trail compared to controls. Similarly, vegetation on the edge of wide hardened gravel and paver trails in tall alpine grasslands in the Australian Alps differed with that further away, including more weeds, while vegetation on the edge of a narrow informal trail or beside a raised metal walkway had near complete cover of native species (Hill and Pickering, 2006).

In a temperate deciduous forest in Belgium, trail type also affected species composition and functional groups depending on the trail surface (Godefroid and Koedam, 2004). This included differences in species richness of forest specialists, disturbance species, geophytes, hemicryptophytes, therophytes, long-term and short-term persistent species and transient species among trails (Godefroid and Koedam, 2004). Of greatest concern was the risk that invasive species along these trail edges could spread further into the forest, particularly from the edge of the gravel (dolomite) and tarmac (asphalt) trails (Godefroid and Koedam, 2004).

The differences in the severity and types of impacts found among trails across the few studies comparing trail types (Table 1, and the results of the current study) in single plant communities are likely to be due, at least in part, to differences in the construction and maintenance, age, presence and the use of the trails as well as differences among the ecosystems studied. The major similarities were that narrow unhardened, usually informal trails, often had less impact on vegetation close to the trail than hardened wider trails. The construction of some types of hardened trails, such as gravel and tarmac trails, could have additional impacts as construction often requires the use of earth moving machinery, such as bobcats, to clear vegetation and re-contour the trail corridor, along with the use of other heavy machinery to deliver and install new surface material which can directly damage vegetation on the edge of the trail (Godefroid and Koedam, 2004).

The maintenance of formal trails may also contribute to changes in understorey vegetation in forests. Natural area managers often maintain a clear corridor wider than the width of trails in forests to prevent overhanging vegetation obstructing sight lines and to reduce the risk of branches falling on the trail (Marion and Leung, 2004). This often reduces the height of plants adjacent to trails (Wimpey and Marion, 2010), changing microclimate conditions (Young and Mitchell, 1994) resulting in changes to plant composition. As a result, the construction and maintenance of formal trails can damage forests (Godefroid and Koedam, 2004; Ballantyne et al., 2016). Therefore, careful consideration must be given as to when and why to harden trails.

The informal narrow bare earth trail did not result in compositional changes to vegetation on the trail edge in the Blackbutt forest. However, there were important impacts on the trail surface (Ballantyne et al., 2014a; Ballantyne and Pickering, 2015b) with the 18.5 km of narrow bare earth trails resulting in the loss of 2 ha of Blackbutt forest and contributing to the internal fragmentation of the forest. Therefore, although the vegetation on the edge of the informal, bare earth trails was the same as the controls, the overall environmental cost of these trails remains high.

4.2. Management implications

For management of recreational trails, key results of this, and the three other studies directly comparing the impacts of different trail types within single plant communities were: (1) impacts on and off trail, including on vegetation, vary with the type of trail, such as between hardened and unhardened trails, (2) hardening tends to reduce impacts on trails such as soil erosion, trails widening and trail incision, but (3) hardened trails can result in greater impacts on vegetation adjacent to trails in some circumstances. These results add to the growing body of generalisations that can be made based on the trail impact literature (Ballantyne and Pickering, 2015a), including that impacts of specific types of trails can vary among plant communities, as well as with topography, slope/trail alignment, physical properties of the soil, climatic conditions and extreme events, as well as the amount and types of use (Leung and Marion, 1996; Nepal, 2003; Dixon et al., 2004; Marion and Leung, 2004; Marion and Olive, 2006; Törn et al., 2009; Pickering et al., 2010b; Wimpey and Marion, 2010; Barros et al., 2013; Monz et al., 2013; Ólafsdóttir and Runnström, 2013; Tomczyk and Ewertowski, 2013a,b; Tomczyk et al., 2016). Increasingly, there are studies that model the relative importance of these different factors on trail condition for specific locations, allowing managers to make better decisions regarding appropriate trail location, design and maintenance as well as regulating different types and levels of trail use (Nepal, 2003; Dixon et al., 2004; Ólafsdóttir and Runnström, 2013; Hawes et al., 2006; Marion and Olive, 2006; Tomczyk and Ewertowski, 2013a,b). However, few of these models currently incorporate the effects of trails on vegetation off trail, as they have focused mainly on the condition of the trail itself. Future research, including using these types of modelling approaches could start to incorporate assessments of factors affecting off trail vegetation as well as trail condition.

It should be noted, that despite the impacts on vegetation adjacent to hardened trails found in the Blackbutt forest and other comparative studies (Godefroid and Koedam, 2004; Hill and Pickering, 2006; Ballantyne et al., 2016), hardening trails remains an effective way to minimise impacts on and off trails in many circumstances. This particularly applies to situations where there are steep gradients, wet areas, easily erodible substrates and/or in areas of high visitor use (Marion and Leung, 2004; Wimpey and Marion, 2010; Ólafsdóttir and Runnström, 2013). Also the current study was not able to incorporate other factors that may account for some of the differences found among the trails including differences in levels of use, and the age of the trails.

5. Conclusion

Comparing the impacts of different trails on vegetation is an important gap in the recreation ecology literature. More research is required to more formally compare the relative environmental impacts of different trails in a wider range of plant communities, especially those already threatened with extinction. Within Blackbutt forest, the two formal trails, gravel and tarmac, had the greatest influence on vegetation on the edge of the trails. It is important for natural area managers to understand the impacts of hardening trails. This may only be appropriate when visitor use and abiotic conditions, such as slope, soil type and rainfall, justify the upgrade of informal trails.

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