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Environmental, safety and management issues of unauthorised trail technical features for mountain bicycling

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ABSTRACT

Mountain biking is a popular activity in urban areas, including in forest remnants in Australia cities. To increase the technical challenge for riders, trail technical features such as jumps, bridges, mounds and ditches, along with informal trails are often constructed without authorisation. We assessed the social, environmental and management challenges associated with the presence of such features, developed a method for assessing them, and then used this method to examine them in an endangered forest within the Gold Coast in Australia. In a 29 ha remnant of Blackbutt (*Eucalyptus pilularis*) forest there were 116 unauthorised features, mostly jumps, ditches and mounds, which collectively resulted in an area of 1601 m^2 of bare soil and 4010 m^2 of undergrowth cleared. Features differed in their size, construction materials used, and their impacts on the environment. Although nearly two thirds had low to moderate safety, most were in moderate to good condition, had fall zones and optional routes for riders. Management options for land managers, in this case a publicly funded University, include (1) feature removal and site rehabilitation, (2) conversion to official features, (3) removal and provision of an alternative location for official features, or (4) maintain the status quo. There are social, financial and environmental benefits and limitations to each of these options highlighting that unauthorised trail technical features are a challenge for planners and managers that often have no easy solution.

1. Introduction

Increasing global urbanisation trends continue to threaten many natural environments (McKinney, 2002, 2008; Sanderson et al., 2002; Williams et al., 2005; Zhao et al., 2006). The retention of relict habitat fragments within the urban matrix can provide critical resources for the maintenance of regional biodiversity (Koh and Sodhi, 2004; Marzluff and Rodewald, 2008; Tratalos et al., 2007) while still providing socio-economic value (Marzluff and Rodewald, 2008). Considerable attention has been given to the importance of urban remnant forests to the conservation of both fauna and flora, particularly with respect to the spatial arrangement, dimensions and physiognomy of these areas (Donnelly and Marzluff, 2006; McKinney, 2008) and their management (Garden et al., 2006; Noss, 2004; Zipperer et al., 1997).

The conservation of urban remnant forests requires an understanding of the biophysical environment but also of how humans utilise these areas. Recreational use of urban and peri-urban natural forests is popular for a range of activities including walking, running, mountain bike riding and horse riding (Arnberger, 2006; Christie et al., 2006; Heer et al., 2003; Florgård and Forsberg, 2006; Hales and Kiewa, 2007; Landsberg et al., 2001; Newsome and Davies, 2009). Mountain biking is an activity that is increasing in popularity in Australia (Chiu and Kriwoken, 2003; Hales and Kiewa, 2007; Newsome and Davies, 2009; Ryan, 2005), New Zealand (Mason and Leberman, 2000), and Europe (Arnberger, 2006; Christie et al., 2006; Heer et al., 2003), and is still popular in North America (Cordell, 2008; Naber, 2008; Schaefers, 2006). In the USA, around 43.3 million people rode a mountain or hybrid bike on back-country roads, trails, or cross country in 2000 (NSRE, 2000). In the United Kingdom there has been a surge in technical mountain biking with riders willing to pay for improved facilities including trail technical feature such a jumps (Christie et al., 2006). In Australia, around 1 million people went bicycling in 2006, although this includes all types of bicycles and locations (ABS, 2008). In south-east Queensland, Australia, around 146,000 people went bicycle riding in a very natural or natural setting in 2007 (Queensland Government, 2007).

Mountain biking is undertaken on a range of public land tenures such as protected areas, designated mountain bike trails and urban reserves (Arnberger, 2006; Chiu and Kriwoken, 2003; Goeft and Alder, 2001; Naber, 2008; Newsome and Davies, 2009; Marion and

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Fig. 1. Examples of mounds, a log jump, a large built jump, a ditch, a camber built up on the corner of a track, and a combination of mounds and ramps from an urban forest remnant on the Gold Coast, Australia.

Wimpey, 2007; Schaefers, 2006; White et al., 2006). It can also occur on private tenures such as commercial mountain bike parks and in ski resorts in the summer (IMBA, 2009; Schaefers, 2006). Mountain bike riding is not homogenous, with different styles of riding, different user motivations, different equipment and potentially different environmental impacts (IMBA, 2009; Marion and Wimpey, 2007; Newsome and Davies, 2009; Schaefers, 2006; Symmonds et al., 2000).

Limited research is available on the environmental impacts of mountain biking than compared with other recreational activities such as hiking and horse riding (Marion and Wimpey, 2007; Newsome and Davies, 2009; Pickering et al., 2010). Impacts associated with the use of existing trails by mountain bike riders include increased soil erosion and compaction, widening of trails and damage to vegetation on trail verges (Chavez, 1996; Chiu and Kriwoken, 2003; Goeft and Alder, 2001; White et al., 2006; Wilson and Seney, 1994). Riding off existing trails can also cause damage resulting in the loss of vegetation and soil surface organic layers leading to exposure of soil, which then results in soil compaction and erosion (Newsome and Davies, 2009; Thurston and Reader, 2001). Mountain bike related soil disturbance can also result in the spread of fungal pathogens (Pickering et al., 2010). Riding off formal trails frequently results in the formation of informal/social/illegal trails (Newsome and Davies, 2009). Many of these environmental impacts are similar in type, although may differ in intensity, to those caused by other recreational activities such as hiking and horse riding (Marion and Wimpey, 2007; Newsome and Davies, 2009; Pickering et al., 2010).

One way in which mountain biking impacts can differ to those of other recreational activities is the construction and use of trail technical features by riders (Newsome and Davies, 2009). These features are constructed on, or near, trails to increase the technical challenge for riders (IMBA, 2009) and are often a part of an increasingly popular style of mountain bike riding called free-riding while also being used by BMX bike riders (IMBA, 2009; NSAA, 2005). Trail technical features include jumps, see-saws (teeter-totters), bridges, ramps, step ups, tables, ditches and mounds (Fig. 1). The type, height and length of these features contribute to the challenge of a trail and are used to rate mountain bike trails. In the five level system used to rate trail difficulty internationally, more difficult trails include those that have features that are up to 0.6 m in height and where the deck width is more than half the height (IMBA, 2009). Very difficult trails have features that are up to 1.2 m in height, and where the deck width is less than half the height, while extremely difficult trails have features that are more than 1.2 m high with an unpredictable width for the deck (IMBA, 2009).

The trail technical features can be constructed from materials such as soil, clay, rocks and timber harvested on site, with some incorporating material brought to the site such as pre-cut timber, nails, cement, bolts and mesh. The construction of features such as ladder bridges, see-saws and ramps often involves detailed planning and a number of comprehensive manuals describe how to construct these features including the types of materials to use as well as safety and liability issues (Webber, 2007). Some private riding venues, ski resorts and public parks provide official trail technical features, often designed, built and maintained in conjunction with mountain bike groups (IMBA, 2009; NSAA, 2005; Ryan, 2005; Christie et al., 2006). In addition to authorised trail technical features built with the approval and often direct involvement of the land manager, unauthorised trail technical features have also been constructed on public land including in peri-urban natural areas (Newsome and Davies, 2009; Ryan, 2005).

A study of a peri-urban national park in Western Australia found that trail technical features were being constructed on both formal multiple use and informally created trails (Newsome and Davies, 2009). A trail specifically cleared and used by mountain bikers was found to be 2.3 km long and associated with 199 m of bypass trail resulting in an informal trail network 2.5 km in length. A total of 18 trail technical features had also been constructed and, on average, mountain bikers had built one trail technical feature every 140 m of informal trail. These actions extend human impacts that are potentially more significant in small reserves. Such activities undertaken by mountain bikers also constitute an additional problem for managers who are trying to cater for a range of recreational activities in peri-urban reserves, while at the same time attempting to protect these forest remnants.

There is limited academic research on the environmental, safety, social and management issues associated with authorised and unauthorised trail technical features (Newsome and Davies, 2009) despite the increasing number of destinations with trail technical features, including many reserves and ski resorts (Christie et al., 2006; IMBA, 2009; NSAA, 2005; Ryan, 2005). Environmental issues that are likely to arise from the construction and use of these features include clearing of native vegetation, harvesting of timber and other vegetation from the site, introduction and dispersal of weeds, soil and rock movement, compaction and erosion, noise, visual effects, water pollution and the introduction of rubbish including material left over from construction activities (Table 1).

Table 1
Potential environmental, social and management issues associated with unauthorised trail technical features.

Environmental issues	Social and safety issues		Management issues
	Positive	Negative	
Loss of native vegetation either through direct clearing or via trampling	Attachment to site	Social conflict with other users	Reduced safety to people at the site due to the presence of structures, their use, and the risk of accidents/collisions
	Presence of new facilities for recreational activity		
Soil movement and compaction, soil erosion	Local community development	Reduced naturalness of site	Increased economic cost associated with maintenance, removal and rehabilitation, increased management (signs, etc.)
Pollution—noise, litter, water from soil erosions and new water body	Presence of alternative lines and fall zones	Reduced safety and personal injury	Liability issues
Associated development of informal trail networks	Ongoing feature maintenance	Deterioration of trail technical features	Need to manage social and environmental impacts
Spread of weeds via bicycles, riders and importation of construction materials		Lack of appropriate trail and feature planning	Need to communicate with varied stakeholders to achieve acceptable outcomes
Wildlife disturbance		Location of features on multi-use tracks	

Social issues associated with such features include positive aspects such as the provision of additional recreational facilities, increasing sense of attachment to the site and increased social cohesion among those who build and use the features (IMBA, 2009). Negative social issues include reduced naturalness of the site for other users, perceptions of inappropriate use of natural areas, decreased naturalness of the site, conflict with other users and safety issues (IMBA, 2009). For agencies responsible for the site there are important potential management issues including visitor safety, costs of removal of features and rehabilitation, or maintenance costs if the facilities are to become 'official', as well as liability issues (IMBA, 2009, Table 1). In addition to an apparent lack of academic studies on trail technical features and their impacts, there appear to be no formal methods for assessing these features despite a detailed literature on how to assess the condition of other facilities such as formal and informal trails (Naber, 2008; White et al., 2006).

In addressing this scarcity of academic information on mountain bike trail technical features, we have assessed the potential environmental, safety and management issues associated with the presence of trail technical features (Table 1). Based on these issues we have developed an assessment methodology for trail technical features that parallels methods used for track and camping monitoring. We then used this methodology to evaluate the extent, characteristics and impacts of different types of unauthorised trail technical features on an urban forest remnant in the Gold Coast, the seventh large city in Australia.

2. Methods

2.1. Site

To assess the potential issues associated with trail technical features, the number and type of all features in an endangered forest remnant on the Gold Coast in the subtropics of south eastern Australia were surveyed. The Gold Coast is the seventh largest city in Australia with a rapidly increasing population, currently estimated at around 500,000. Despite the Gold Coast local government area still retaining more than 45% of its natural habitat intact there has been large scale clearing of vegetation in the city precinct associated with its growth. This has resulted in a heterogeneous landscape of natural habitat remnants, some of very high conservation value, within a variable urbanisation matrix. For example there are small remnants of tall open forest of Blackbutt (*Eucalyptus pilularis*) on metasediments on the Gold Coast that are recognised as an endangered regional ecosystem (RE 12.11.23) within Queensland (EPA, 2007). Prior to extensive clearing for urban and agricultural use, this community covered 7757 ha comprising 36 areas ranging in size from 1 to 3391 ha (mean = 215 ± 103 ha) on the Gold Coast (mapping of vegetation done use data from EPA, 2007). In 2003 there was less than 767 ha comprising 194 fragments ranging in size from 0.2 to 65 ha (mean = 3.95 ± 0.56 ha) (mapping of vegetation done use data from EPA, 2007). Of the remaining Blackbutt habitat 565 ha (74%) is currently owned by government although this does not necessarily preclude them from further development pressures where land is sold to developers.

One of the largest remaining areas of Blackbutt forest on the Gold Coast is the ±29 ha of Blackbutt forest on the campus of a large publicly funded University (Griffith University, Gold Coast campus). This forest remnant provides habitat for a diverse native faunal community including threatened species such as the green-thighed frog (*Litoria brevipalmata*), wallum froglet (*Crinia tinnula*) and koala (*Phascolarctos cinereus*), as well as regionally significant populations of the native yellow-footed antechinus (*Antechinus flavipes*), squirrel glider (*Petaurus norfolcensis*) and swamp rat (*Rattus lutreolus*) (author observations, DERM, 2009). It also forms part of a regional urban biodiversity network connecting a number of other nearby remnants (DERM, 2009). Two other communities are contained within the larger Blackbutt area, a swamp paperbark woodland of *Melaleuca quinquenervia, Eucalyptus tereticornis* and *Lophostemon suaveolens*, and a tall open woodland of *Eucalyptus siderophloia* and *Corymbia intermedia*.

Due to the subtropical climate and recreational opportunities presented by a range of parks, reserves and other areas of semi-natural to natural ecosystems on the Gold Coast, activities such as walking, dog walking and mountain biking are popular (Hales and Kiewa, 2007). Although currently not formally sanctioned and without official facilities, there appears to be regular use of the remnant Blackbutt forest on the Griffith University Gold Coast campus for these activities, in addition to others such as a limited amount of trail bike riding. These activities are undertaken on an extensive informal trail network which includes many unauthorised trail technical features, which were the focus of this study.

2.2. Development of an assessment methodology for trail technical features

To assess environmental, social and management impacts of trail technical features on the Griffith University, Gold Coast cam-

Table 2
Details of information collected to assess environmental, safety and management issues associated with unauthorised trail technical features.

Data collected on	Assess, measure, derived	Details/options
Trail technical feature		
Type of structure	Assess	Bridge, camber, ditch, drop-off, jump, ladder, log, mound, see-saw, other or a combination of structures
Size of feature	Measure	Total length, maximum width, minimum width, maximum height/depth, minimum height/depth
Predominate material used in construction	Assess	Concrete, drums, local vegetation, metal, soils, imported timber or other materials
Site details		
Location general	Assess	On track, in a cleared area, in natural vegetation
Location detail	Measure	GPS location (WGS84 datum)
Trail information		
Trail type	Assess	Narrow, one person, two people walking side by side, three people, proper 4wd road
Size of trail	Measure	Width, depth
Length of trail	Derived	Data from trail assessment used to calculate length in GIS (ArcView)
Slope	Assess	Flat, gentle, mild, severe
Aspect	Measure	Degrees
Soil type	Assess	Clay, gravel, loam, sand, bedrock or other
Condition of understorey	Assess	Poor, good, or weedy verge
Canopy type	Assess	Closed, mixed or open
Environmental impacts		
Width of area disturbed	Measure	Width of bare soil, width to understorey, to shrub layer and to tree trunks
Total area disturbed	Derived	Width multiplied by the length of the feature
Native vegetation removed to construct feature	Assess	True/false
Roots exposed	Assess	True/false
Presence of rubbish	Assess	None, appliances, vehicles, electronics, glass, metal, plastics or other
Safety factors/and other management issues		
Condition of feature	Assess	New, good, moderate, non-functional or remnant
Safety of feature	Assess	Low, moderate, high, very high
Presence of signage	Assess	True/false
Presence filters or choke points	Assess	True/false
Optional lines around feature	Assess	True/false
Fall zones	Assess	True/false

pus, an assessment method was developed using a mixture of categorical and quantitative indicators (Table 2). This included basic information about each feature including the type of structure, its size and what it was predominantly constructed from (Table 2). Although some features such as jumps and ditches can be constructed together, they were treated as separate features for the purposes of this study. The location of each feature, as well as the slope, aspect, soil type, understorey vegetation condition and canopy type of the area around it were recorded. If the feature was on a trail, this was recorded along with other information about the trail including the type of trail and the width and depth of the trail (Table 2).

Likely environmental impacts of trail technical features were assessed using methods similar to those used to assess trails and campgrounds (Table 2). They included quantitative measures such as width of bare ground, width to intact understorey, width to intact shrub layer and width to intact forest (tree trunks). Qualitative measures included if vegetation had been removed to construct the feature, if roots were exposed and the presence or absence of rubbish.

Some social and management issues were also assessed directly from the feature. These included the condition of the feature, and the presence of features considered important for safety by mountain biking organisations (IMBA, 2009) (Table 2). The condition of the feature was recorded as it affects both the current and future management requirements of the site but also the potential risks associated with their use. The condition scores were assigned based on a subjective classification of the deterioration of the features (e.g. weathered, broken timber, eroded sand on jumps, etc.). This was assisted by visual signs of recent use or improvements to the features. The overall safety of the features was assessed as a function of the risk associated with its use, which was dependent on the presence of specific safety features recommended by mountain bike organisations. These measures were categorical and based on the judgment of the recorder. Information was recorded about signage, trail filters (structures to reduce rider speed and/or limit access such as gateways or qualifiers such as a rock garden, rock step to narrow entrance to the feature), optional lines (alternative easier routes around the features) and fall zones (area next to feature where riders could fall without hitting rocks, branches or stumps) (IMBA, 2009).

2.3. Assessment of trails and trail technical features in a Blackbutt forest remnant

In May 2009 in the 29 ha Blackbutt forest remnant on the Gold Coast campus of Griffith University, all unauthorised trail technical features were located, principally by visually searching from all trails within the forest. One author with previous experience in trail assessment methods assessed all the features to maintain consistency in the use of categorical measures. She was involved in the design of the categories and in previous reviews of assessment methods. Some categories such as condition and safety were based on the perceptions of the recorder. Data were recorded using the

Table 3
Number of trail technical features with quantitative characteristics. Data for 116 trail technical features from an urban forest remnant on the Gold Coast, Australia.

	TYPE	#	Camber	Ditch	Jump	Log	Mound	Other	Bridge	Comb.[a]
	# features	116	8	18	63	6	13	2	2	3
Condition=	Remnant	4	1			1	1			1
	Not functional	2							1	1
	Moderate	36	2	8	17	1	6	1	1	
	Good	73	5	10	46	4	6	1		1
Safety=	Low	56	8	10	24	4	9	0		1
	Moderate	53		7	37	1	4	2	1	1
	High	59		8	39	2	4	2	2	2
Optional lines?	# true	83	6	18	51	2	4	1	1	
Fall zones?	# true	63	5	13	37	1	4		1	2
Vegetation removed?	# true	106	7	17	59	5	11	2	2	3
Rubbish present?	# true	69	2	15	44	1	5	0	0	2

[a] Comb. There were three combination features, which were (1) a bridge (fallen tree), drop off and double ramp/jump (over the tree), (2) a drop off and bridge and (3) a combination of mound and jump/ditch.

ArcPad (ESRI, version 7.0) interface on a Trimble Juno ST handheld GPS. Individual trail technical features were captured in a point feature layer in the field and their associated attributes recorded using a series of drop down menus, numerical entries and tick boxes. All informal trails were also mapped in the field using the GPS with vertices being captured every 3 m to draft a map of the trail network. Following field data capture, all trail attributes (i.e. width and distance measures) were linked with trail technical features at the site using the spatial join function and the final database file was exported for analysis in Microsoft Excel and in SPSS 16. The areas of bare soil, and areas without undergrowth, shrubs or trees were calculated by multiplying the maximum length of a feature by the width of each type of disturbance for that feature.

2.4. Data analysis

Data were analysed to determine if there were significant differences in environmental impacts, potential social and safety issues for managers among the different types of trail technical features and for all types of features with four or more examples in the remnant (e.g. camber, ditch, jump, log and mound). One-way ANOVA in SPSS 16 were used to compare quantitative measures among different types of trail features. The quantitative measures: maximum length of feature, width to natural understory, width to shrub layer and width to trees, were log transformed ($\ln(x+1)$) to satisfy the assumptions of the ANOVA, while all disturbed area measures (extent of bare ground, area with no undergrowth, shrub or trees) were square root transformed. For maximum soil width, it was not possible to transform the data such that it would satisfy the assumptions of the ANOVA and hence a non-parametric one-way Kruskal–Wallis test was used.

Differences among types of trail technical features were compared using Chi-squared tests for the quantitative data, with a null hypothesis that there were no significant differences among types of features. This included the quantitative measures: condition of features (moderate and good); the safety of features (poor, moderate and good) and if the answers were true or false for the presence of optional lines, fall zones, if building the feature involved vegetation removal and if any type of litter was present.

3. Results

3.1. Types of trail technical features

A total of 116 technical trail features was recorded in the 29 ha urban forest remnant, giving a density of 4 per ha (Fig. 2, Table 3). The most common type of technical trail features were jumps which accounted for just over half of all the features (Table 3). Other types of features in this remnant were bridges, cambers, ditches, logs, mounds, others, and three combinations of features. Less than half (51) of the features were located on the informal trails themselves, with the rest in cleared areas adjacent to trails. Features tended to be clustered, with several jumps present in the north west of the patch on slopes, while several clusters of mounds, jumps and ditches occur in the south east of the forest adjacent to a 4wd road and near a main access point (Fig. 2). There were few features on the one person trails in the north east of the forest where prior to the construction of a car park, high school and university residences 2 years ago, there was limited road access.

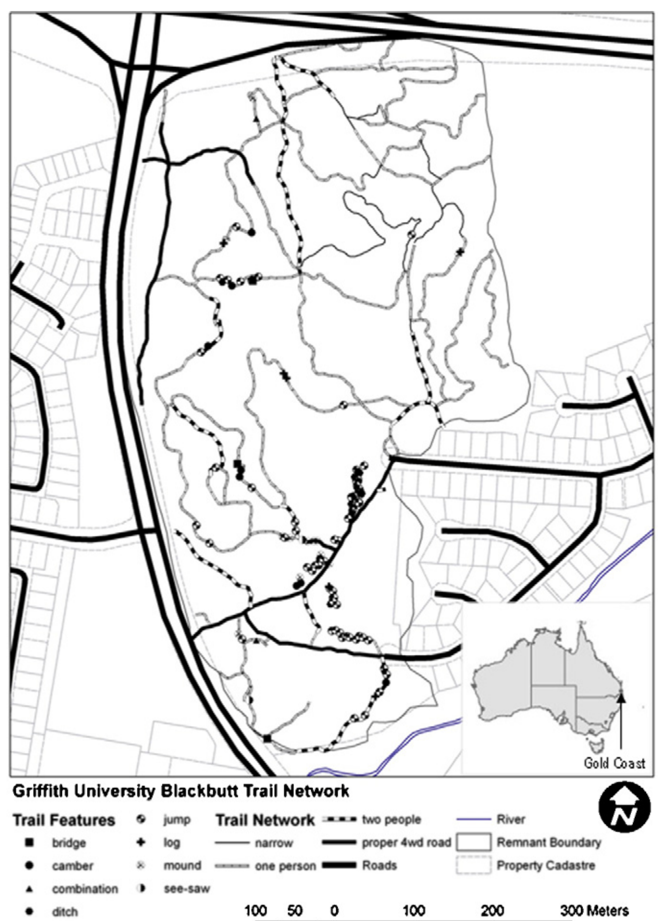

Fig. 2. Location of unauthorised trail network and trail technical features in an urban forest remnant on the Gold Coast, Australia.

Table 4
Quantitative measures in meters of 116 trail technical features from an urban forest remnant on the Gold Coast, Australia. The five most common features (first five in the table) were compared using One-Way ANOVAs if appropriate, or the equivalent non-parametric test (Kruskal–Wallis test) if the assumptions of the test could not be satisfied even after transformation of the data. P values in bold are significant. Letters in front of mean values indicate types that are not statistically significantly different using Tukeys post hoc tests.

	Length	Max. height/depth	Max. width	Width bare ground	Width to understory	Width to shrub layer	Width to trunks
F-value (d.f. = 4)	**6.559**	36.715	22.137	6.231	3.030	4.004	1.991
P-value	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**0.021**	**0.005**	0.101
Transf. or non-param.	ln(*x* + 1)	No trans. required	Non-param.	No trans. required	ln(*x* + 1)	ln(*x* + 1)	ln(*x* + 1)
Camber							
Mean ± SE	a 4.74 ± 0.80	ab 0.47 ± 0.6	1.03 ± 0.30	a 2.30 ± 0.59	a 5.95 ± 0.90	a 5.21 ± 1.19	5.02 ± 0.78
Range	2.74–8.60	0.26–0.70	0.42–3.10	0.27–5.05	2.30–9.50	0.84–10.30	2.23–8.60
Ditch							
Mean ± SE	ab 2.86 ± 0.39	c −0.32 ± 0.5	3.14 ± 0.56	b 7.03 ± 0.69	a 15.55 ± 1.37	b 16.42 ± 1.44	13.66 ± 1.54
Range	0.21–5.80	−0.5 to −0.83	0.31–6.00	1.60–11.70	6.70–23.00	7.50–24.80	1.10–22.10
Jump							
Mean ± SE	bc 2.27 ± 0.14	a 0.64 ± 0.05	2.29 ± 0.11	bc 5.43 ± 0.37	a 15.39 ± 1.24	ab16.31 ± 1.50	13.98 ± 1.35
Range	0.7–5.25	0.25–2.20	0.75–5.50	0–12.30	0–38.80	0–65.00	0–38.80
Log							
Mean ± SE	b 0.73 ± 0.29	b 0.26 ± 0.05	2.14 ± 0.24	ac 2.09 ± 0.83	a 5.37 ± 0.67	ab 5.44 ± 1.33	4.39 ± 0.82
Range	0–1.90	0.12–0.48	10.15–2.86	0–5.10	3.10–7.40	2.13–9.90	2.30–7.05
Mound							
Mean ± SE	ac 2.33 ± 0.32	b 0.29 ± 0.04	1.84 ± 0.20	ac 3.52 ± 1.13	a 9.97 ± 2.34	a 9.99 ± 2.50	10.59 ± 2.81
Range	0.90–4.30	0.10–0.60	0.90–3.10	0–15.25	0–24.30	2.00–25.50	1.50–32.65
Combination							
Mean ± SE	7.07 ± 4.93	0.67 ± 0.18	1.29 ± 0.10	1.72 ± 0.49	11.83 ± 2.62	10.85 ± 2.60	6.08 ± 3.86
Range	1.45–16.90	0.32–0.90	1.10–1.45	0.90–2.60	6.60–14.80	5.80–14.45	2.10–13.80
Other							
Mean ± SE	2.24 ± 0.42	0.39 ± 0.24	1.37 ± 0.17	1.77 ± 0.04	4.54 ± 0.27	6.38 ± 0.58	4.03 ± 0.28
Range	1.82–2.65	0.15–0.62	1.20–1.53	1.73–1.80	4.27–4.80	5.80–6.95	3.75–4.30
Bridge							
Mean ± SE	5.55 ± 1.53	0.77 ± 0.32	0.62 ± 0.04	6.38 ± 2.58	10.13 ± 3.04	9.63 ± 2.50	8.27 ± 3.10
Range	3.95–8.60	0.19–1.28	0.55–0.67	1.95–10.90	4.60–15.10	5.00–13.60	4.40–14.40
Total							
Mean ± SE	2.67 ± 0.19	[a]0.56 ± 0.4	2.19 ± 0.10	4.94 ± 0.31	13.22 ± 0.83	13.80 ± 0.97	11.92 ± 0.89
Range	0–16.90	0.10–2.20	0.31–6.00	0–15.25	0–38.80	0–65.00	0–38.80

[a]Only mean of heights and hence does not include depth for ditches data.

The size of structures was highly variable with average dimensions of 2.7 m long, by 2.2 wide and 0.56 m high or 0.33 m deep for ditches (Table 4). Some were much bigger, with the longest a combination at 16.9 m, the widest a ditch at 4.8 m, the tallest a jump at 2.2 m in height while the deepest was a ditch at 0.8 m below average soil level. The different types of features vary significantly in size (Table 4). Logs tended to be shorter than most other types, jumps were higher and ditches lower than most other types, while ditches tended to be wider and cambers narrower, than most other types.

The most common type of material used in construction of the features was local soil which was used for nearly all the jumps and ditches with 82 of the features principally made of this material. Soil was also brought into the site but this could only be discerned if the features were recent additions to the network. Local vegetation including the use of paperbark (*M. quinquenervia*) Blackbutt (*E. pilularis*) and Black she-oak (*Allocasuarina littoralis*) was noted while coarse woody debris (fallen logs, etc.) was the next most common material, used for the cambers, jumps and logs. Wood brought to the site was the predominant material used to construct the more complex trail technical features such as the bridges, drop offs and one of the jumps. Concrete and metal were used infrequently in construction of the jumps.

3.2. *Environmental impacts*

When trail technical features are unauthorised two major problems arise. The first is the inappropriate modification of existing and often multiple-use trail networks, and the second is the creation of informal trails, which is an activity that is often associated with non-approved trail technical feature development. A total of 8.6 km of informal trails were mapped within the remnant ranging in size from those that could accommodate vehicles to those wide enough to be used by only a single person (Fig. 2). Some of these trails are of long standing, including the wider trails, while others appear to have been developed recently. The total area affected by the trail network is 1.8 ha or 6% of the total remnant area.

Environmental impacts directly associated with the 116 trail technical features include: damage to existing vegetation including the shrub and understorey, cutting of trees or harvesting of fallen timber to construct features, exposure of bare ground, movement of soil, introduction of materials used in the construction of the features, and general introduction of rubbish through littering. Nearly every feature involved the removal of some vegetation (107 of the 116 features, Table 3), with no significant difference in frequency with which vegetation was removed among different types of features (Chi-squared, $P = 0.7211$) (Table 3).

Table 5
Area in m^2 of natural vegetation impacted by 116 trail technical features from an urban forest remnant on the Gold Coast, Australia. The top five features in the table were compared using One-Way ANOVAs on square root transformed data. *P* values in bold are significant. Letters in front of mean values indicate types that are not statistically significantly different using Tukeys post hoc tests.

	Area of		Area without	
	Bare soil	Undergrowth	Shrub	Trees
F-value	5.300	4.416	3.692	3.296
P-value	**0.001**	**0.002**	**0.005**	**0.014**
Camber				
Mean ± SE	ab 10.71 ± 2.91	abc 26.31 ± 4.87	abc 26.33 ± 8.73	abc 23.21 ± 4.03
Sum	85.70	210.51	210.66	185.69
Ditch				
Mean ± SE	ac 20.85 ± 3.96	b 46.94 ± 8.79	b 48.98 ± 8.93	b 41.74 ± 8.07
Sum	375.26	844.95	881.59	751.33
Jump				
Mean ± SE	ac 13.16 ± 1.40	b 35.74 ± 3.59	b 38.37 ± 4.48	b 33.17 ± 3.95
Sum	829.33	2251.90	2417.42	2089.44
Log				
Mean ± SE	b 1.78 ± 1.19	c 4.18 ± 1.98	c 4.99 ± 2.84	c 3.80 ± 2.01
Sum	10.65	25.10	29.96	22.82
Mound				
Mean ± SE	bc 9.90 ± 3.31	abc 29.15 ± 9.86	abc 29.93 ± 10.45	abc 26.77 ± 8.85
Sum	128.68	378.94	389.15	348.04
Combination				
Mean ± SE	12.20 ± 8.04	58.06 ± 27.47	52.35 ± 23.81	27.36 ± 12.16
Sum	36.60	174.17	157.04	82.09
Bridge				
Mean ± SE	42.42 ± 26.19	63.97 ± 33.77	59.65 ± 29.38	55.27 ± 34.35
Sum	127.27	191.90	178.94	165.82
Others (2)				
Mean ± SE	3.96 ± 0.81	10.25 ± 2.47	14.01 ± 1.36	9.11 ± 2.29
Sum	7.92	20.49	28.02	18.22
Total				
Mean ± SE	13.81 ± 1.34	35.33 ± 2.96	37.01 ± 3.31	31.58 ± 2.90
Sum	1601.41	4097.95	4292.78	3663.45

There were significant differences among the types of features in their impacts on soils, the undergrowth, shrub layer and tree layer (Table 5). Logs were associated with the least area of disturbance be it a measure of area without undergrowth, shrub or trees or with bare ground. Ditches and jumps in contrast, were associated with larger damaged areas. An average ditch involved the loss of 47 m^2 of undergrowth, while jumps were associated with the loss of around 36 m^2 of undergrowth. The combined effect of all 116 features, was the loss of an area of 4098 m^2 of understory, 4292 m^2 of shrubs and 3666 m^2 of forest itself and an area of 1601 m^2 of bare soil. In all these impacts account for a further disturbance to 0.43 ha of the remnant habitat.

Some features by their very nature involved the movement of soil. The jumps, mounds and ditches all involved the movement and compaction of soil, in some cases large amounts. The deepest ditch was 0.8 m below the general surface while the tallest mound was 0.6 m higher than the general surface. None of the features involved exposed roots, unlike the tracks they were often associated with. Rubbish was present at slightly over half the features (60), with metal (25) glass (15) and plastic (11) the most common types of rubbish. More of the logs, cambers, ditches and mounds had rubbish than expected, while fewer jumps had rubbish than expected (Chi-squared, $P = 0.001$).

3.3. Safety and condition of trail technical features

Based on an overall assessment of safety, only 5 features were given a high safety rating, 53 were moderate, and 56 were allocated a low safety rating. More cambers and jumps had lower safety ratings than expected, while there were more mounds and logs with a high safety rating than expected (Chi-squared, $P = 0.002$) (Table 3). Nearly all of the features (73), particularly the jumps, mounds, ditches, cambers were either in good condition (73) or in moderate condition (37). There was no significant difference in the proportion of features of each type that were in moderate or good condition (Chi-squared, $P = 0.3884$). Four features, a camber, combination, log and mound were in disrepair while two features, a bridge and combination were no longer functional. Potentially reflecting the unauthorised nature of these features, was the lack of signage and/or filters (choke points) that let riders know what was ahead, or to slow them down as they approached a feature. Many (84), but not all, of the features were associated with alternative routes so that riders could avoid the feature, and 64 had fall zones. Few logs and mounds had alternative routes, while more than expected numbers of jumps and ditches did (Chi-squared, $P < 0.001$) (Table 3). There were no significant differences in the proportion of types of feature with fall zones (Chi-squared, $P = 0.053$) (Table 3).

4. Discussion

4.1. Environmental and safety issues of trail technical features

Mountain biking has emerged as new recreational activity and sport around the world in the last 20 years (Chavez, 1996; Hales and Kiewa, 2007; Webber, 2007). The indications are that mountain biking, especially as a non-organised recreational pursuit is set to continue increasing in popularity into the future (Hales and Kiewa, 2007; IMBA, 2009). This growth in mountain biking activity is placing increasing pressure on current trail infrastructures and peri-urban environments in Australia (Ryan, 2005), the USA and many parts of Europe. Also, the presence of mountain bikers on multi-use trails can be a source of social conflict (Carothers et al., 2001; Chavez, 1996; Kerr, 2003; Schuett, 1997). Many natural area users are concerned about erosion ruts and gullies on trails (Foreman, 2003; Horn et al., 1994). Braking, skidding and sliding activities, that are frequently associated with the use of trail technical features, loosen the track surface, displace soil down slope and create ruts, berms or cupped trails (Cessford, 1995; Foreman, 2003; Webber, 2007).

A combination of increasing demand for mountain biking facilities and what is perceived by mountain bikers to be a slow response from managers to respond to this need has lead to bikers adjusting existing trails and developing trails that suit their needs. Trail technical features, designed to enhance the character and difficulty of trails, are frequently constructed by mountain bikers and come in many forms (Newsome and Davies, 2009; Ryan, 2005). A major problem for reserve-managers is that these trail technical features, and often associated informal trails, are often badly located, poorly built and represent a significant hazard to many riders and other users (Newsome and Davies, 2009).

The presence of large numbers of trail technical features in the remaining natural forest remnant on the Gold Coast campus of Griffith University clearly demonstrates that the conservation value of urban remnants may be reduced by this aspect of recreational use. The features have degraded the environmental value of the forest with adverse effects on vegetation and soils. The area and type of impacts varied among the features, with jumps and ditches involving the movement of large amounts of soil, the creation of bare areas potentially leading to impacted areas without an understorey or trees. Many of the features such as the bridges and combinations, but also some jumps, involved the harvesting of wood and/or importation of material (timber, sand, etc.) into the forest.

These environmental impacts are in addition to those caused by the presence and use of existing informal trails (Marion and Wimpey, 2007; Newsome and Davies, 2009, Pickering et al., 2010). There was over 8.6 km of informal trails within this forest remnant used by mountain bike riders, hikers and trail bike riders. Informal trails result in the exposure of soil, soil erosion and compaction, and reductions in the area of understorey, shrubs and trees (Bhuju and Ohsawa, 1998). Mountain bike riding on and off trails often results in these types of environmental damage, particularly in areas of high usage, steep slopes, and where trails are susceptible to damage (Marion and Wimpey, 2007; Newsome and Davies, 2009; Pickering et al., 2010).

It is possible that the construction and use of trail technical features have other negative environmental impacts such as on animal behaviour by altering foraging patterns and resulting in more vigilance behaviour. Studies of mountain bike riders on trails have found some impacts on animal behaviour, although they were often the same, or not as great, as those due to hikers, who appeared more likely to leave the trail (Marion and Wimpey, 2007). In addition to the environmental impacts on soils and vegetation associated with the trail technical features, there are also safety and potentially liability issues associated with their presence that require a management response.

4.2. The management challenge of unauthorised trail technical features

There are several options open to land managers in dealing with existing unauthorised trail technical features and associated informal trails. They fit within the direct, indirect, collaboration, and resource hardening options outlined by Chavez (1996) in managing recreational use. Management could take a direct approach and remove the features and rehabilitate the sites and associated informal trails. This is likely to address safety and liability risks associated with the presences of such features and would also reduce some of the environmental impacts. However, as the presence of the features in large numbers indicates that there is already an unmet need/desire for them in the area (Ryan, 2005), they may be rebuilt thereby requiring ongoing policing and site rehabilitation. An education and or policing strategy might reduce the chance of their being replaced, but how successful such an approach may be is not clear as the original features and trails were not authorised in the first place. This approach also does not address the positive social dimensions associated with trail technical features from a mountain biker's perspective. This demonstrates the complexity of urban ecosystems where the inclusion of assessment of biophysical and social aspects in adaptive management frameworks is required (Cadenasso et al., 2006; Pickett et al., 2008).

A second option is the provision of official trail technical features at the same location, along with converting the informal trails into formal trails. This could require the upgrading some of the existing features and trails to better meet safety and environmental standards. This approach is similar to resource hardening when dealing with riding on tracks (Chavez, 1996). Such a strategy may address the unmet need for such features and trails in the local area, provide many of the positive social benefits of such features, and if incorporating better design principles, reduce some of the negative environmental effects. Working with local mountain bike groups to provide appropriate facilities and trails has worked well in many cases (IMBA, 2009) but there are also other users to consider as walking appears to be the primary focus of many users of urban forest remnants (Flogård and Forsberg, 2006; Hales and Kiewa, 2007; Roovers et al., 2002). This option may address the negative sentiments shown towards the mountain bike riders by other users as it may be possible to zone areas within the remnant for certain types of recreational activities. However, free riding features and trails may not be consistent with the desired usage of the forest by the land owner (Griffith University), and these may detract from and discourage alternative usage that is desired, and it has initial and ongoing costs.

A third option is the provision of alterative sites with official constructed and maintained trail technical features and trails. This approach has been taken by parks and local governments in Canada (IMBA, 2009), New Zealand (Mason and Leberman, 2000) the USA (Chavez, 1996) and in Australia (Newsome and Davies, 2009). It seems to work well when there is cooperation between managers and user groups, particularly when formalised in development of construction strategies with formal groups representing users. In some instances this option may not be available or appropriate, and it does involve costs (financial and time) to the mangers and possibly user groups.

This third option was used elsewhere in Australia recently. In 2003 and 2006, International Mountain Bicycling Association trail building experts have been hosted in Australia to make presentations to land managers rider (Ryan, 2005) and conduct a series of trail building workshops (WAMBA, 2007). In 2006 a workshop was organised by the Western Australian Mountain Biking Association, International Mountain Bicycling Association, Western Australian Department of Conservation and Environment and the Department of Sport and Recreation. The 4-day workshop demonstrated world's best practice techniques for sustainable trail design to staff and mountain bike representatives and culminated in 500 m of new downhill trail being established at a dedicated site. The 'Goat Farm' in south-west Western Australia in an outer peri-urban area located near John Forrest National Park, Perth has been an informal riding area for many years and was recently designated as a mountain biking area with downhill-specific trails and cross country trails. The Department of Environment and Conservation and the Western Australian Mountain Biking Association worked together to develop the Goat Farm as a technical riding area. Maintenance and development of the trail system is still in progress and there are plans for an interpretive shelter, signage, car park, bike racks and maintenance racks to be provided. The Goat Farm is part of the Department of Environment and Conservation's ongoing trail management strategy to provide suitable mountain biking opportunities to meet demand in a manner where environmental impacts can be controlled. The Goat Farm thus provides a technical and challenging alternative to riders who might otherwise use the adjacent John Forrest National Park, ostensibly reducing the burden of non-approved technical riders in the John Forrest National Park as discussed earlier in this paper.

A fourth option is to leave the features 'as is'. This does not involve immediate costs of removal and rehabilitation, but also does not address the social and liability risks associated with their presence in this forest, or stop further environmental damage to the forest. It may even result in the construction of more features, and proliferation of the informal track network, if a lack of response was perceived as an opportunity for expansion by users.

4.3. Assessment method for trail technical features

The methods used in this paper provided useful information on a range of environmental, safety and management issues associated with unauthorised trail technical features. The assessment of features was relatively rapid to undertake and did not require much prior training. With an appropriate sampling regime, data on trail technical features can be used for a range of univariate and multivariate analyses. The methodology had the added benefit of capturing the spatial distribution of features, facilitating its use to address future conservation questions where spatially explicit data are required (Garden et al., 2006). The current method could also be expanded to cover other potential environmental impacts such as the spread of weeds, other types of pollution such as water contamination and noise, and the effects of trail construction and use on animal populations. It could also be modified to make it suitable for long-term monitoring of such sites.

4.4. Who builds unauthorised trail technical features and why?

The methods used here were limited to data that could be collected directly from the features. It therefore did not address many important social issues including who built the features and why. Social survey methods such as intercept interviews, focus groups, e-mail surveys and video observations could be used to find out more about patterns of use, the motivations, attachment and desires of riders and other users of the forest, as well as attitudes of other members of the local community. Surveys/interviews of riders has been used to provide information on mountain bikers including demographics, preferences for trails and other facilities, environmental awareness, perceived impacts, crowding, likely attitudes towards restrictions on activities and, actual and perceived conflicts among users (Heer et al., 2003; Hollenhorst et al., 1995; Seeland et al., 2002). Another on site method that has been used is direct video observation of site visitors in order to assess usage patterns, and potential for conflict among user groups in urban and peri-urban reserves (Arnberger, 2006). Mail and e-mail surveys of members of riders groups and via outdoor and cycling shops, has been used to assess mountain bike rider preferences for trails, perceptions of their own and other users impacts, as well as obtaining demographic information about riders and their levels of experience (Chiu and Kriwoken, 2003; Goeft and Alder, 2001; Mason and Leberman, 2000; Symmonds et al., 2000).

It is possible that those who construct and use unauthorised trail technical features may not have the same motivations, demographic profiles and ecological approaches as other groups of mountain bike riders. Surveys of some mountain bike riders indicates a moderate to strong ecological awareness/concern for the environment (Heer et al., 2003; Symmonds et al., 2000), a preference for natural rather than artificial materials in the construction and maintenance of tracks (Symmonds et al., 2000), a preference for trails in natural settings (Goeft and Alder, 2001) and concern that inappropriate use may result in restrictions on access to natural areas for mountain bike riders (Webber, 2007). The development of user codes of behaviour by land managers and mountain bike groups, reflects a desire on the part of many riders to limit negative social and environmental impacts of riding. Certainly the building of unauthorised trail technical features breaches the IMBA code of practice (IMBA, 2009). The presence of so many unauthorised features on the forest remnant on the Gold Coast is consistent with a common pattern of large social and environmental impacts often due to the inappropriate behaviour by a small subset of users. It may also reflect a greater likelihood of inappropriate use of urban and peri-urban parks as compared to more remote protected areas.

5. Conclusions

The construction and use of unauthorised trail technical features by mountain bikers has clear environmental, safety and management issues, while operating within an as yet unquantified social setting. In recent years there has been an expansion of sporting activities, such as mountain biking, taking place in natural areas and especially those in the peri-urban setting. Such users have specific requirements and it would appear that they do not always have a responsible attitude towards environmental integrity. The solution of what to do, however, is not always obvious and will vary with the environment, location of a site, who is responsible for managing it, the riding community and the broader community. What is apparent is that turning a blind eye to the presence of such features in natural area in and around cities is unlikely to be the optimum solution, for land managers, users of the reserve and conservation.

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