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The Influence of Trail Design on the Impacts of Walkers, Mountain Bikers and Multi-use Trail Users: An Environmentally Responsible Approach

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ABSTRACT: Trail design and building guidelines are essential tools for influencing the behaviour—and therefore the environmental impact—of users of walking, mountain biking and multi-use recreation trails. Yet, these tools are often not explicitly considered in research that monitors their environmental impact. This is the first study to investigate the role of trail design in shaping how walkers and mountain bikers utilise mountain biking, walking and multi-use trails. The research differentiates trail feature types to examine how they shape user behaviour and, therefore, environmental impact. This observational study uses time-series photographic imagery to examine behaviour and impacts over 12 months. Impacts at each site were examined using current trail building design guidelines. The findings show that shortcuts were commonly employed to avoid long sections on walker-only trails, and to cut across meandering tracks on the multi-use trails in the mountain bike park. Trail spread occurs when walkers use the edges of the trail to avoid rough or uneven surfaces such as stairs and tree roots. Depressions in the trail before technical mountain biking features such as berms and drops were also apparent. Further observations include toilet paper and litter on the walking trails. The research furthermore indicates the unintended environmental impacts when trail users did not adhere to specific trail features or did not use the trails as intended. Unique trail design principles are required where walkers and mountain bikers use the same trails, and this paper provides recommendations for improving trail design.

KEYWORDS: trail design; walking; mountain biking; environmental responsibility

Introduction

Globally, bushwalking has been considered the most popular outdoor recreation activity in national parks and state forests for decades (Carlsen & Wood, 2004). In recent years, mountain biking, trail running, and orienteering activities have gained popularity, particularly near urban areas (Land Use Planning & Coordination Unit, 2015; Ng, Leung, Cheung, & Fang, 2018; Norman, Pickering, & Castley, 2019). The increase in popularity of outdoor recreation activities contributes to the development of adventure tourism opportunities (Chang & McCreesh; Highfill & Franks, 2019). Practices such as responsible tourism aim to strengthen communities by addressing the social, economic and environmental impacts of tourism and is accomplished by governments and their stakeholders implementing sustainable tourism practices (Chan, 2010; International Conference on Responsible Tourism in Destinations, 2002). This study explores the use of trail building guidelines in park assets to discern if the trail design influences walkers and mountain biker's trail user behaviours. This study also identifies how trail designs hinder or improve trail users' ability to implement environmentally responsible behaviours.

Trail design plays a crucial part in ensuring the environmental sustainability of outdoor recreation areas (Ballantyne & Pickering, 2015a, 2015b; Pickering & Norman, 2017). However, a review by Ballantyne and Pickering (2015b) showed that studies mostly assessed the development of formal and informal trail systems and their impact on different vegetation types. Well-established trail design and building guidelines exist for walking and mountain bike trails and are used to plan and develop trails in natural areas (Appalachian Mountain Club, 2008; IMBA, 2001; Webber, 2004). Though the International Mountain Bicycling Association (IMBA) guidelines recognise that trails may be multi-use, there is a clear focus on either walking or mountain biking in each guide. This study differentiates trails into different types, examining changes in trail conditions and features over time as they relate to environmental conditions and user behaviours. This is the first study to investigate the role of trail design in shaping how walkers and mountain bikers utilise mountain biking, walking and multi-use trails.

Governments, walking and mountain biking groups have developed minimal environmental impact guidelines. The principles of these guidelines promote environmentally responsible behaviours such as staying on the designated trail, disposing of litter and human waste, and adhering to park management strategies (IMBA, 2001; Leave No Trace Australia, 2020; Tasmania Parks and Wildlife Service, 2018; Trail Hiking Australia, n.d.). The environmental impacts caused by walking and mountain bike trail use include soil compaction, soil erosion (feet, bicycle wheels and water), weed transfer and trail spread. (Appalachian Mountain Club, 2008; Ballantyne & Pickering, 2015a; Newsome & Davies, 2009; Ng et al., 2018; Pickering, Rossi, & Barros, 2011). Due to trail user traffic, the natural process of surface erosion is aggravated by soil compaction (Pickering, Hill, Newsome, & Leung, 2010), emphasising the importance of trail users staying on designated trails. Soil erosion is ecologically significant due to the slow process of soil creation (Marion, Leung, Eagleston, & Burroughs, 2016). Soil compaction from trail users can hamper seed germination and penetration by plant roots, which further emphasises the importance of trail users staying on marked trails (Marion et al., 2016). Weed transfer escalates when bare soil is exposed, facilitating the transportation of weed seeds to other vegetated areas (De Rouw, Ribolzi, Douillet, Tjantahosong, & Soulileuth, 2018). Trails are also damaged if used during wet weather events, due to the mud and the soft condition of the trails (Leung & Marion, 1996; Newsome & Davies, 2009; Pickering et al., 2010). Though the environmental impacts of trail users are well-known, studies have not explored how trail design can influence trail user behaviours that cause these issues. This study will explore environmentally responsible management of park assets by monitoring the impacts of trail design on walkers and mountain biker's trail user behaviours.

Literature Review

Trail design principles for walking and mountain bike trails

Well-established walking and mountain bike trail design and building guidelines exist (Appalachian Mountain Club, 2008; Council of Standards Australia, 2001a, 2001b; Webber, 2004, 2007). In Australia, walking trail standards detail facility recommendations for each classification, signage and infrastructure depending on geographic features, e.g. stairs, bridges, and ladders (Council of Standards Australia, 2001a, 2001b). The Appalachian Mountain Club trail guidelines describe ways to create walking trails at any gradient and ways to expel water from the trails (Appalachian Mountain Club, 2008). The IMBA trail building guidelines, initially informed by the Appalachian Mountain Club, address ways to manage mountain bikers through trail design (Webber, 2004). The foundation principles of mountain bike trail building focus on ways to expel water from trails. Therefore, the focus is on the gradient of the landscape, the gradient of the trail, and trail building techniques which reduce the amount of water being trapped on the trail by using contours such as 'grade reversals' to force water to drain off the trail (Webber, 2004). Using trail anchors (e.g., large rocks and logs) corrals trail users and helps keep walkers and mountain bikers on the trails and reduce mountain bikers' speed. Gateways, also known as 'chokes', encourage mountain bikers to reduce speed. However, these should not reduce the 'flow' of the trail, otherwise an informal trail may be created by the riders (Webber, 2004). Multi-use trails for walkers and mountain bikers are common (Koemle & Morawetz, 2016; Pickering & Rossi, 2016; Queensland Government, 2021a). To date, studies have not identified environmental impacts within trail design specifications, or trail building guidelines that inform trail design and development. This study presents an alternative approach, addressing the environmental impacts in outdoor recreation areas that are not yet used in research. This study draws from conservation photography and the practical application of trail building guidelines to develop a unique methodology to address environmental impacts on walking and mountain bike trails and trails developed for multiple uses. This methodology could be practically applied to guide future trail designs.

Researchers have used photography to address environmental impacts (Ward, 2008). Initially used in environmental conservation advocacy, conservation photography has been used to study wilderness and natural areas since the early 1900s, and it played a role in the establishment of numerous national parks in the United States (Ward, 2008). Photo images, often taken in remote areas of wilderness, were brought to government officials to enhance their understanding of environmental concerns (Schultz & Svajda, 2016; Ward, 2008). Photographs taken at regular intervals from the same location can reveal the precise nature of change (Loizos, 2011). In more recent environmental studies, photo and satellite imagery have been used to address ecological impacts in waterways, reefs systems, and outdoor recreation trails (D'Antonio, Monz, Newman, Lawson, & Taff, 2013; Greer, Day, & McCutcheon, 2017; Kellner et al., 2017; Macgregor, 2011; Needham & Rollins, 2005; Ng et al., 2018). Photo imagery was used to detect waterway erosion due to a white water river racing event (Jones, Pilgrim, Thompson, & Macgregor, 2008). Photo simulations showing familiar trails with various crowd levels can stimulate conversations with trail users about acceptable levels of crowding (Needham & Rollins, 2005). Photo imagery can report unauthorised trail use and non-compliance to leash-laws for dog walkers (Greer et al., 2017; Kellner et al., 2017). D'Antonio et al. (2013) used photo simulation to determine the attitudes of trail users toward the visual impact of vegetation loss and informal trail systems being created on walking trails. In this study, photos were taken at three intervals over 12 months to monitor the environmental impacts of trail users. To the knowledge of the current researchers, this is the first study in which photography has been used to create time-series data to examine trail user behaviour and impact.

Study site

The study site for this research was the Baldy Mountain State Forest Reserve and Herberton Range State Forest, situated on the Atherton Tablelands, Far North Queensland, Australia. Herberton Range State Forest and Baldy Mountain Forest Reserve are 7297 hectares–the latter adjoins the 6547 additional hectares of forest of the Herberton Range National Park. The Atherton Tableland rises 700m above sea level, providing a cool tropical climate with a monsoonal wet season (November to March). The forest comprises eucalypts, she-oaks, bloodwoods, mahogany, and grass trees with some sections of teak, blackbutt, and tallowwood trees left from the forestry industry that used to occupy the area (Queensland Government, 2021b). Environmental management strategies used by the Queensland Parks and Wildlife Service include the Planned Burn Program to reduce fuel and manage weeds in nature reserves (Leeson, 2006) and minimum impact messaging for trail users (Queensland Government, n.d.-a).

Observations occurred on the Baldy Yabi Circuit Walk and the Atherton Forest Mountain Bike Park trails, which cross the Baldy Mountain State Forest Reserve and Herberton Range State Forest. Baldy Yabi Circuit Walk is a network of 8.5 km of mainly steep walking trails offering views at three lookouts. Two points access the Baldy Yabi Circuit Walk, both with off-road gravel car-parking (Queensland Government, n.d.-a). Walking trails are graded using a class system from 1 (no experience needed) to 5 (specialised skills required) (Council of Standards Australia, 2001a). The Baldy Yabi Circuit Walk is a Class 4 grade and is recommended for experienced walkers, as there are rough trails with limited signage that may require navigation skills, and the trail gradient is only limited to the environmental and maintenance considerations (Queensland Government, n.d.-b). Class 4 trail users are likely to expect opportunities for solitude with limited contact with others, and there may be access to toilets, car parking, drinking water and information shelters (Council of Standards Australia, 2001a). Atherton Forest Mountain Bike Park is jointly managed by Queensland Parks and Wildlife Service and the Tablelands Cycle Sports. Atherton Forest Mountain Bike Park has 54.4 km of one-directional, interconnecting trails, of which 14.5 km is a 'green' trail, providing multi-use trail access for mountain bikers, walkers and dog walkers (Queensland Government, 2021a; Tableland Cycle Sports, 2022). Mountain biking trails use a trail difficulty rating system with key characteristics to guide each category. Five grades exist, with 'white' the easiest trail, 'green' the easy trail (available to walkers and dog walkers), 'blue' the intermediate trail, and 'black diamond' the difficult trail, and 'double black diamond' the extremely difficult trail (Webber, 2004). The Atherton Forest Mountain Bike Park technical difficulty scale ranges from easy, 'green' to intermediate, 'blue' grade single track, with five very difficult 'black diamond' level tracks, with alternative sections on three 'blue' trails (Queensland Government, 2021b).

Methods

Sampling

The current time-series observational study identified changes in trail conditions at three intervals over 12 months. Photography was used to document the trails at specific times of the year. The baseline photo observation was taken in September 2018 during the 'dry season', in February 2019 during the 'wet season', and the following September 2019 during the 'dry season'. The rainfall conditions during each photo observation are described in Table 1. By comparing the sites during different seasons, it is possible to distinguish trail considerations that emerge during the tropical seasons that impact on trail user behaviour.

Table 1: Rainfall Atherton 2009-2019

Observation	Month/Year of Observation	Recent rainfall	10-year (2009-2018) average rainfall for the relevant month
1	September 2018	5mm	20.1mm
2	February 2019	*447.4mm	269mm
3	September 2019	**9.6mm	19.4mm

Note. * Trail observations were completed in the first two days in February after significant rainfall occurred at the end of January with 447.4mm rainfall.
** Trail observations occurred on the first days of September, with 9.6mm rainfall reported for August. From Bureau of Meteorology (2020).

Trail building features identified for this study include trail design, drainage, technical features, trail building materials, and trail conditions. Trail descriptions and trail analysis were developed using the overlapping trail building principles from the walking and mountain bike trail building guidelines (Appalachian Mountain Club, 2008; Council of Standards Australia, 2001a, 2001b; IMBA, 2001; Webber, 2004). Table 2 outlines the trail design characteristics from each guide, and these guidelines have been used as part of the assessment of how trail design can influence trail user behaviour. Impacts at each site were tested using these trail design characteristics (see Table 2). The observation survey was based on elements in the trail building guidelines identified in Table 2 and included categorical items as well as options to detail each section of trail.

Observation sites were not randomly selected but instead each site incorporated notable trail designs and features. Observations were used to detect how the trail design and features may encourage or deter the trail user from using minimal impact trail use. The trail user behaviour was assessed by detecting soil compaction by walkers and mountain bike tyre tread patterns caused by not keeping to designated trails or using sections of trails to navigate trail features. Other evidence of use was also observed, e.g., litter and toilet paper. Impacts addressed in this study include keeping to marked tracks, trail user impacts on the trail, sanitation practices, and litter.

An iPadOS-based tablet was used to take photo images of each section of the trails. The locations of the observation sites were referenced in a Global Positioning System (GPS). A spreadsheet with photos of each trail section from each observation was placed alongside the survey data. The study used a non-invasive approach to monitor trail sites over a twelve-month period. Photos of each section of trail were compiled from the three observations and were compared over time. Using this approach meant no environmental impacts were caused by the research (e.g., no transect markings were used for precise measurements of erosion, etc.) Moreover, using time-series observations allowed observations of seasonal differences in terms of trail conditions to be noticed and changes in trail user behaviours.

Table 2: Key Elements of Walking and Mountain Biking Trail Design and Building Guidelines described in Appalachian Mountain Club (Appalachian Mountain Club, 2008; Webber, 2004, 2007)

Key element	Appalachian Mountain Club	International Mountain Bike Association
Erosion control		
Drainage- remove water from the trail.	Swales- shallow depressions across the trail. Wide on the uphill side of the trail, narrowing to the outside ditch of the trail. Drainage dips- Earthen water bars. Used on trails with less than 10 -12 per cent gradient. Reinforced water bar- made with wood or rock across the trail to divert the water off the trail into a ditch. Used on steep grades of more than 12 percent gradient. The steep slope, the more water bars needed. Cross ditch- Fortified edges of trail either side of a small stream or runoff section.	"The half rule"—When the trail transverses the side of a hill. Trail grade does not exceed half the grade of the hillside slope. On average, trail grade should not exceed 10 percent. Avoid flat areas. Grade reversals–trail subtly rises and falls, directing water to the low point and then off the trail. Trail tread area to have a 5 per cent fall towards the outside of the trail to drain water. Short steep sections (e.g., 15–25 percent) need to consider: • Fortification to protect the trail. Annual rainfall • Low-impact users only (walkers and mountain bikers) • Number of users • Soil type • Grade reversals • Difficulty level • Half rule
Stabilisers- hold soil on tread area in place.	Steps- vertical rise made with either wood or rock. Crib stairs- long steps terraced with wood and crushed stone.	Rock mat–Natural-looking, artificial materials matted together with steel meshing. Crushed stone and fill materials. Identify soil type–sand, silt, and clay as a sign of soil characteristics when wet, when dry and its drainage ability. Rock retaining walls to support the out slope of the trail.
Hardeners-fortification of trails in wet areas.	Bog bridges- timber plank to elevate trail above muddy area. Turn pike- sections of trail boxed in with timber, filled with rocks and covered soil. Stepstones- rock set in muddy sections of trail. Rock treadway- rocked pathway covered with crushed stone.	Rock mat–natural-looking, artificial materials matted together with steel meshing. Identify soil type–sand, silt, and clay as a sign of soil characteristics when wet, when dry and its drainage ability. Flagstone paving- large flat stones used to create trail sections Stone pitching- tightly fitted stones up on their side. Raised tread construction- large rocks engrained in the tread, medium

Key element	Appalachian Mountain Club	International Mountain Bike Association
		rocks locked into place, then capped with crushed stone or aggregate. Steep trails over rock slabs.
Trail user elements		
Definers-channel or direct foot traffic on the designated trail.	Scree- rocks each side of the trail used to reduce erosion. Steps- vertical rise made with either wood or rock.	Trail anchors- large rocks, logs, trees, and other obstacles can create physical and visual barriers.
Reduce speed- use objects to encourage riders to wash off speed.	N/A	Chokes/Gateways are a gradual narrowing of the trail using rocks and plants. Trail anchors- large rocks, logs, trees, and other obstacles can create physical and visual barriers.
Trail design to manage visitors.	N/A	Easy trails near the entrance of the trails with different trail experience. Provide more difficult trails further away.
Buffers.	Allow for a buffer zone to reduce impact on protective zones by using a single approach, to have a single point of impact (e.g., access to lake).	Used to create a barrier between adjacent lands.
Elevation gain.	Wide switchbacks, fortified with steps. Avoid short switchback to reduce monotony.	Narrow turns and switchbacks used to increase elevation using drainage techniques. Uphill corners - crown loading- trail building technique used to disperse water off an ascending corner to avoid the water channelling down the trail.
Technical features		
Drop- offs.	N/A	Drop off- a technical feature which incorporates a natural ledge with a drop. Drop-off size to be developed dependent on the flow and skill-level of the trail.
Rock gardens.	N/A	The trail travels over rocky areas to increase the challenge.
Berms.	N/A	Contoured compact dirt used for fast cornering.
Water crossing/ford.	N/A	The trail crosses dry or wet water crossing.

Key element	Appalachian Mountain Club	International Mountain Bike Association
Whoop.	N/A	Small, smooth dirt hills built close together and smooth dirt hills built close together that also expel water off the trail.
Table- top.	N/A	A beginner jumps -a short section of trail raised with a jump entry and exit. It is built as a ‘table’ so riders can also roll over the feature.

Data analysis

Trail sites were evaluated from notes recorded at each of the three trail observations and by analysing the three sets of photographs taken over twelve months. The indicators examined at each of the sites included: identifying the trail feature and its application of trail building guidelines (Table 2), the intended use of the feature (technical/skill feature or trail design feature), drainage type, surface, turns, and trail condition. Environmental impacts were identified by evidence of erosion, change in vegetation and soil compaction. Due to the growing popularity of building multi-use trails, some sections of the mountain bike trails in the study areas are used by walkers and dog walkers, hence the trails were analysed collectively to identify trail user behaviour across a range of trails designs. The photographic analysis was conducted by the lead researcher (LS) and a member of the local cycling club with experience in mountain biking and trail building.

Trail conditions were identified as *good*, *fair*, and *poor*. Trail conditions were recorded as *good* when there were no unplanned rock or root protrusion, water flowed adequately from the trail and no muddy puddles or dry indentations were identified. *Fair* was recorded when some rock and/or tree root profusions were identified, and minimal water erosion on the trail was present, while trails were recorded as *poor* when substantial rock and/or tree root profusions were present, and noticeable water erosion took place on the trail.

Results

Description of the trail systems

A total of 46 sites were included in the analysis, 19 sites were on the Baldy Yabi Circuit Walk and 27 sites were in the Atherton Forest Mountain Bike Park. Eighteen of the 27 sites in the mountain bike park were on 'green' trails jointly accessed by walkers, dog walkers, and mountain bikers. Table 3 identifies the types of facilities offered to trail users at each reserve according to the Australian Walking Trail Standards.

Table 3: Facilities offered for the Baldy Yabi Circuit Walk and Atherton Forest Mountain Bike Park

Trail system	Baldy Yabi Circuit Walk		Atherton Forest Mountain Bike Park
Access point	Yabi Mountain	Mount Baldy entrance	Rifle Range Road
Information shelter	√	√	√
Car park	√	√	√
Drinking water	X	√	X
Toilets	X	X	X
First aid kit	√	√	X
Minimum impact messages on a sign at the trailhead	Protect plants and animals Take your rubbish with you Dogs on leash always- Fines apply		Stay on marked trails and formed roads to prevent erosion and vegetation damage Keep tracks in good condition by not riding during or immediately after wet weather Take your rubbish with you
Safety messages	Stay on the trail and observe danger signs. Bring water, hat, and sturdy footwear.		Do not leave the trails- shooting range nearby Give way at road crossings Wear safety gear

Trail system	Baldy Yabi Circuit Walk	Atherton Forest Mountain Bike Park
	Walk in the cooler part of the day. Allow yourself enough time to return in daylight	Beware of creeks rising in heavy rain Sections slippery when wet Give way to other riders Keep note of your location when riding Avoid skidding and sliding around turns and down slopes, as this may cause collisions with other trail users and damage trail surface

Note: *Three permanent snake bite kits in sealed containers were added to the walking trails between Observation 1 and Observation 2.

Table 4 shows the distribution of observation sites across the Baldy Yabi Circuit Walk and Atherton Forest Mountain Bike Park. Table 4 also describes the trail design and features of the walking trail and mountain bike trail observation sites. Evidence of a park managed hazard reduction fire was documented on the lower section of the Mount Baldy side of the circuit walk at Observation 1. Seasonal changes in the vegetation were notable between each interval, with significant rainfall in the lead up to Observation 2. It was notable that the encroachment of vegetation on the trails and short-cuts reduce some trail spread between Observation 1 and Observation 2 and then the short-cuts were introduced by trail users at Observation 3.

Table 4: Trail design and features of the walking trail and mountain bike trail observation sites

Trail descriptions	Variables and definition	N (%)
Trail	**Baldy Yabi Circuit Walk**	
	Walkers only.	19 (41.3%)
	Atherton Forest Mountain Bike Park	
	'Green' easy trail - multi-use trails for walkers and mountain bikers.	18 (39.1%)
	'Blue' with some 'black' options- Mountain bikers only.	9 (19.6%)
Surface	Compacted surface from trail use - Dirt exposed and no additional materials added.	22 (47.8%)
	Loose rocks or gravel surface - small rocks or gravel either from the soil or added to the trail.	8 (17.4%)
	Armoured–Artificial materials - Concrete slab, faux rock prefab sections for stairs or mountain bike rock mat.	3 (6.5%)
	Armoured–Natural materials - Rocks from around the trail have been used to create a feature.	9 (19.6%)
	Armoured- Natural existing, exposed rock.	4 (8.7%)
Drainage	Trail width angles inwards towards the bank- wash sheds to the inside of the trail.	6 (13%)
	Trail width angles outwards to allowing water to flow to expel off the trail.	11 (23.9%)
	Reverse grade/knicks–trail constructed with a slight undulation to allow water to pool and quickly expel from the trail.	7 (15.2%)
	Whoops- a series of smooth dirt hills built close together that also expel water off the trail.	2 (4.3%)
	Natural gradient- flat or slope.	20 (43.5%)

Trail descriptions	Variables and definition	N (%)
	Crown loading- trail building technique used to disperse water off an ascending corner to avoid the water channelling down the trail.	0
Technical or trail feature	Steps- natural or faux rock.	3 (6.5%)
	Drop- technical.	3 (6.5%)
	Berm- contoured compacted dirt used for fast cornering.	3 (6.5%)
	Water crossing/ford- Trail crosses dry or wet water crossing.	5 (10.9%)
	Whoops- small, smooth dirt hills built close together.	3 (6.5%)
	Open flow trail- Relevantly flat or untechnical.	9 (21.7%)
	Trailhead/ lookout.	5 (10.9%)
	Climb- uphill slope.	9 (19.6%)
	Table-top–A beginner jump short section of trail raised with a jump entry and exit.	1 (2.2%)
	Anchors.	3 (6.5%)
	Flagstone paving.	2 (4.3%)
Turns (Mountain bike park only. One-directional trail features)	Climbing turn- trail ascends while turning.	2 (4.3%)
	Switchback- flat, tight cornering.	0
	Descent turns- trail descends while turning.	3 (6.5%)
	Open trail.	41 (89.1%)

Table 5 documents the trail conditions at each site at each of the observations. Similar results are reported for the walking trails throughout the observation period. The majority of mountain bike trail sites that reported *good* or *fair* then reported as *fair* or *poor* during Observation 1 ('dry season') then reported as fair or poor due to the condition of the trail during the wet weather (Observation 2), however, returned to *good* at Observation 3.

Table 5: Trail conditions for walking and mountain bike trails over the 3 observations (12 months)

Observation	Trail	Trail condition			
		Good	Fair	Poor	Total
1	Baldy Yabi Circuit Walk	8	7	4	19
	Atherton Forest Mountain Bike Park	18	7	1	27
2	Baldy Yabi Circuit Walk	7	8	4	19
	Atherton Forest Mountain Bike Park	13	6	8	27
3	Baldy Yabi Circuit Walk	8	7	4	19
	Atherton Forest Mountain Bike Park	17	7	3	27

Observations of trail users' behaviour

Not keeping to marked trails

On the walking-only trail, shortcuts were apparent in some sections. Shortcutting to avoid long sections of the designated trail occurred where old sections of the trail were re-routed to traverse across the mountain. Even though there was a well-established new formal route to use, it was evident by the soil compaction and loss of vegetation cover that the old section of the trail was still used by some walkers. This shortcutting occurs even in sections with 'closed for regeneration' signage. Shortcutting was also apparent on the multi-use mountain bike trails but was more apparent during the dry season. During the wet season, the shortcuts become overgrown and unused. Shortcuts occurred on flat terrain to exit the main trail onto an adjacent road, or to avoid completing a hairpin turn (cut across a tight snaking section of the trail).

Avoiding rough and uneven surfaces

Trail spread occurs when trail users use the edges of the trail to avoid rough or uneven surfaces. On the walker-only trail, small protruding rocks, steep climbs, and stairs were avoided, and instead, the smooth, newly compacted soil on the edges of the trail was used. All three observation intervals indicated that walkers were avoiding the use of the steep, naturally armoured stairs wherever possible. For example, walkers chose naturally compacted soil directly next to the stairs (see Figure 1). On the very steep Mount Baldy side of the walking circuit, a significant number of materials and infrastructure, including prefabricated stairs, natural rock stairs, stretches of cement foundations and rock armouring, was used to mitigate environmental impacts. However, trail diversions used to avoid trail features (e.g., stairs), and obstacles (e.g., small tree roots) continued to be visible at each observation. Stairs with wide sections of 'scree' (rocks each side of the trail used to reduce erosion) and 'cairns' (rock piles used to help guide trail users to stay on the trail to allow for regrowth to occur) successfully kept walkers on the trail. This was evident by the amount of vegetation growing through the rock armouring. Trail sections with rock armouring restricted trail users to the stairs (Figure 2). Evidence of a planned fire management burn at the bottom section of the walking trails is presented in Observation 1.

Figure 1: Walkers on the Baldy Yabi trail create trail spread by accessing less technical options off-trail. Sites 8, 14, 15 during Observation 1

Note: Photograph taken by Leah Stevenson

Observation
‘Dry’ season
September 2018

Observation 2
‘Wet’ season
February 2019

Observation 3
‘Dry’ season
September 2019

Figure 2: Baldy Yabi Circuit Walk- Site 2, Observations Over 12-Months. Cairns used as definers on walking trails to encourage walkers to use a single step

Note: Photograph taken by Leah Stevenson

Steep trails

On the Yabi Summit side of the walkers-only trail, there was a minimal number of materials and infrastructure used. Several sections of marked trail that travelled directly uphill had evidence of soil compaction, exposed rock, and tree roots. Trail spread was occurring due to trail users gravitating to smoother sections of the trail (Figure 3).

On the multi-use and mountain bike-only trails, there were depressions caused by soil loss before a technical feature. For example, on the mountain bike only trail, a high-speed berm (a berm on a downhill section where the rider can enter the berm at high-speed) showed soil erosion because of braking mid-berm, progressively becoming more prominent over the 3 observations. On the multi-use trail, several small drops built with small rocks showed evidence of hard breaking before the drop. The landing of the drops could not be seen on entry, resulting in hard breaking by some riders.

Drainage

In the mountain bike park, outward drainage was used in most sections of the trail, which allows water to shed. These sections of trails had little evidence of water accumulation and no evidence that trail users were riding outside the designated trail area. However, some drains on the multi-use mountain bike trail used inward drainage to allow water into a depression on the inside of the trail before being channelled across to the outside of the track. These inward drains were used in wet sections of the trail that transverse across a hillside. As a result, additional re-enforcing of the outside of the trail was needed, creating a wider ‘environmental’ footprint. These sections of trail stayed wetter and tyre depressions were evident.

Figure 3 shows an ascending corner of the multi-use trail when the drainage gradient is inadequate. The lack of crown-loading has caused the rainfall to be directed onto the trail, and a significant erosion line was apparent through the centre of the trail. Trail users avoided the eroded section, causing the trail to be widened to create a new mainline on the right of the eroded section. Though drainage issues are apparent, no significant changes to the trail condition were identified over 12 months.

Trail closures

Evidence of fresh, superficial tyre tracks were observed in the multi-use mountain bike trails during the park closure due to wet conditions (Observation 2). The superficial print of a mountain bike tyre was evident in boggy sections of the trail. It should be noted that Baldy Yabi Circuit Walk was not subject to the same trail closure requirements, so could not be compared across different trail areas.

Evidence of other impacts

Toilet paper was most apparent along the Mount Baldy side of the walking trail. Toilet paper was observed during all three trail observations. Significantly more toilet paper was observed behind and near the Mount Baldy trailhead during Observation 3. Notably, at the first lookout, there was a strong smell of human faeces, indicating that trail users have open-defaecated close to the lookout (Observation 3). At the mountain bike park, toilet paper was observed behind a log on the far end of the car park during all three observations. No toilet paper was found within the mountain bike park. Litter (other than toilet paper) was identified around the Mount Baldy car park area during all three observations, with more litter found during Observation 3. Most of the litter was crisps packets and confectionary wrappers. Figure 4 outlines the trail characteristic based on the trail building guidelines and the trail user impacts identified across the different trails in this study.

Observation 'Dry' season September 2018	Observation 2 'Wet' season February 2019	Observation 3 'Dry' season September 2019

Figure 3: 'Green' Multi-Use Trail. Lack of Crown Loading to divert water off the trail causes the trail to widen. Site 41 observed over 12 months

Note: Photograph taken by Leah Stevenson

Baldy Yabi Circuit Walk and Atherton Forest Mountain Bike Park

	Walkers-only	Multi-use trails – walkers & mountain bikers ‘Very easy’ and ‘easy’ trails	Mountain bikers-only ‘Intermediate’ and ‘difficult’ trails
Trail characteristics	Most of trail is very steep- using stairs, steep natural and cemented armoured trails. Open meandering trails. Some full and part benching used. Snake bite kits on trail, water at one car park.	Gentle gradient and smooth surface. Majority of trail use full and part benching. Tight meandering/snaking trail design. Built across the hillside and some low-lying areas. Varity of trail features e.g., berms, creek crossings, grade reversals, open flow trail. Some obstacles – roots, rocks, logs.	Some steep inclines and declines for rider experience. Trails built across hillsides to promote free draining trails. Majority of trail use full and part benching. Varity of trail features e.g., berms, drops, open flow trail.
Trail user impacts	Short-cuts on steep section of trail. Trail spread caused by walkers avoiding small roots and rocks. Toilet paper and litter on at the trailhead and on the trail. Walkers redirect trail beside stairs to avoid them.	Short-cuts on meandering sections of trail and to exit onto gravel road. Trail on flat and in wet areas- eroded, muddy, multiple routes. High speed section before unarmoured technical feature e.g., small drop causing erosion depression in trail.	High speed section before unarmoured technical feature e.g., berms, steep rock drops, logs. Inward drainage directs mountain bikers to the soft outer edge of the trail.

Figure 4: Summary of trail characteristics and trail user impacts, Baldy Yabi Circuit Walk and Atherton Forest Mountain Bike Park

Discussions

Responsible tourism principles emphasise the importance of limiting environmental impacts (Vu, 2015). This study examined how trail design can influence trail user behaviour on walker-only, multi-use and mountain bike-only trails to better inform trail design for multi-use trails that encourage environmentally responsible behaviours. Results show that trail design influences trail users' impact behaviours (see Figure 4). In exploring the impact of trail design on trail user behaviours this study has shown that park managers could further encourage trail users to be environmentally responsible by improving trail design. This study contributes to the extant literature via the practical and theoretical implications outlined in the following sections.

Minimal impact behaviours

Previous studies have examined the impacts of walkers and mountain bikers (Ballantyne & Pickering, 2015a, 2015b; Newsome & Davies, 2009; Pickering et al., 2010; Pickering & Norman, 2017). However, this is the first study to monitor the impacts of trail user behaviour over time and to compare it with trail building guidelines. The present study showed trail design influences the impact behaviours of trail users.

As outdoor recreation areas near urban areas grow in popularity, park managers need to consider ways to reduce the effects of trail user impacts on the natural environment (Ng et al., 2018). Shortcutting by walkers on multi-use mountain bike trails needs to be addressed. Mountain bike trail design often uses narrow switchbacks/hairpins to assist riders to climb steep sections of a trail without increasing the gradient of the trail. In some situations, shortcutting by walkers may be inevitable, and stairs may be needed. Unstable rock armouring/scree could be also used to deter walkers and reduce environmental damage. Ensuring there are enough exit points to the main road is required to minimise shortcuts. A study by Marion and Reid (2007) concluded that, by creating infrastructure such as steps, design detracts from the visitor experience and trail users felt superficial infrastructure caused them to feel less connected with nature. For example, the installation of site hardening was uncomfortable to look at and even reduced the emotional connection visitors felt to the natural environment (Cahill et al., 2008). Also, the provision of stairs can be costly and they permanently alter the natural setting (Dawson & Hendee, 2009; Stankey, Cole, Lucas, Petersen, & Frissell, 1985). However, site hardening may be necessary to protect valuable ecosystems. Walking trail guidelines promote the use of trail features that reduce erosion caused by rainfall (Appalachian Mountain Club, 2008). However, future trail building guidelines for walking trails should encourage trails to be built across mountains with a reduced trail gradient to reduce erosion, like the designs used in mountain bike trails.

Shortcutting on walking trails was identified as a major issue. On the walking trail in this study, evidence of soil compaction revealed that walkers avoid stairs and cut out lengths of the trail, mainly employing the old 'direct lines', to reach the walking trail lookouts. Soil compaction is common on walking trails (Pickering et al., 2010), which means making sure walkers keep to trails is essential to avoid trail spread. The current study showed that steps with wide sections of scree can remedy this issue because walkers prefer to use the least technical option on the trail, making steps the preferred option. Walking trail design guidelines emphasise the importance of not creating narrow switchbacks and encourage wider turns fortified with steps, where necessary, to prevent shortcutting (Appalachian Mountain

Club, 2008). Mountain bike trails can meander within reasonable proximity of other trails, with narrow turns and switchbacks, and there is a need to consider the other parts of the trail for safety (Webber, 2007). Further assessment of achieving a balance between these two design principles is needed.

The physical impacts of off-road mountain biking have been identified from hard braking, steep slopes and riding when trails are wet (Chiu & Kriwoken, 2003). This study supported these findings. Breaking holes at the bottom of drops usually occurs due to novice riders getting kicked up by the back wheel of their bikes, which causes them to lock their brakes when the wheel returns to the ground. Opportunities to reduce speed before such features should help to reduce erosion by hard braking. The erosion on the small jumps and whoops occurs when mountain bikers with less technical skills brake on the obstacle instead of before the obstacle. Furthermore, trail degradation increased where there was surface water (Webber, 2007). Different riding styles can create various forms of trail damage (Newsome & Davies, 2009). Signage encouraging mountain bikers to avoid hard-breaking, and to ride on the firm sections of trail have been developed in some regions (Neumann & Mason, 2019). Further development of trails to reduce the speed of mountain bikers before soft features, and the use of armouring when there is no-line-of-sight below a trail feature, seems warranted.

Trail spread

Trail spread, a common environmental impact, is caused when walkers avoid eroding or sodden sections of track, retreating to the edges of the trail to avoid wet or difficult surfaces (Appalachian Mountain Club, 2008). As slope steepness increases, the force of water also increases, and in combination with foot traffic, this causes erosion hazards for trails (Appalachian Mountain Club, 2008). In this study, trails that used direct lines up the hill, without trail anchors, had significant trail damage. Trail users are causing trail spread and erosion, with multiple trail lines across directly uphill. It is essential for guide trail users to stay on designated trails, and to ensure trail user behaviour does not exacerbate the issue.

Mountain bike trails mainly incorporated an outward drainage system and were more likely to be graded as *good* compared to inward drainage graded as *fair* or *poor*. Not only does the trail design need to consider potential natural environmental impacts, e.g., water erosion, but it also needs to consider how people will use the feature to ensure it does not cause additional erosion.

Litter and toilet paper

A review by Stevenson, Allen, Mendez, Sellars, and Gould (2020) identified human waste to have potential environmental and public health impacts in outdoor recreation areas. In this study, toilet paper was observed along the walking trail, mainly on the Mount Baldy side of the trail system (including the carpark). The lack of access to nearby toilets may be influencing this behaviour (see Table 3); however, the same issue with toileting was not observed at the mountain bike park. Park managers may need to consider educating trail users on toilet etiquette to reduce this behaviour on trails (Stevenson et al., 2020). Notably, walkers are prepared in that they take toilet paper with them on the trails; however, the toilet paper being left on the trail demonstrates a reluctance to move off the trail or take their litter with them. Further research into this issue may help park managers better understand the motivation for leaving toilet paper on the trail and thereby reduce toilet paper litter on the trails.

Trail user behaviours can be addressed through the indirect promotion of visitor education programs such as the 'Leave No Trace' approach used by walking/hiking and mountain biking organisations (Trail Hiking Australia, n.d.; Webber, 2004). The 'Leave No Trace' approach focuses on improving conservation attitudes through awareness (Leave No Trace Australia, 2020). While park rangers can enforce penalties through the State Penalties Enforcement Regulation 2014, it is mainly used when visitors deliberately interfere with native animals, for instance, feeding them (Queensland Government, 2019). Research shows trail users tend to support environmental conservation (Dawson & Hendee, 2009); however, this study indicated that some trail users lack the awareness or skills to follow through with environmentally responsible behaviours while on the trails. Further research using health promotion behavioural principles may be useful to improve trail user environmental impact behaviours.

Trail closures

Trail closures can reduce the impact of trail users on tracks during wet conditions (New South Wales Government, 2011). In this study, some mountain bikers were not respecting trail closures. Park management regulations may need to be considered by monitoring trail use to improve adherence (Marion & Reid, 2007; Stankey et al., 1985). However, regulation through law enforcement has its limits due to the size of natural areas and limited resources for land management officers to enforce policies (Marion & Reid, 2007). Management options discussed by Chiu and Kriwoken (2003) showed both mountain bikers and other users considered bicycle education/information and a code of conduct as being good management options (Chiu & Kriwoken, 2003). In this study, minimal impact message provided at the trailheads are not being adhered to. For example, trail users are asked to take their litter with them and not ride on trails during trail closures. Additional minimal impact strategies are needed to promote the long-term sustainability of trail systems to reduce erosion, trail damage, and litter.

Recreation area managers are required to accommodate the growing numbers of recreationists without risking the ecological integrity of the location (Schultz & Svajda, 2016). Monitoring the impacts of visitor use is critical to the long-term environmental sustainability of natural environments (Belnap, 1997; Monz, Pickering, & Hadwen, 2013; Stevenson et al., 2020). A study of trail conditions before and after trail running events emphasised the importance of trail maintenance to keep trails in good condition (Ng et al., 2018). Design that produces low maintenance is important in trail building (IMBA, 2001). A study by Monz et al. (2013) noted that the key areas for improvement were to minimise the impacts from visitors, including managing visitor behaviour, to improve trail design and maintenance, provide minimal impact trail user education via signage and park manager engagement with trail users, and to build the capacity of trail user groups via the promotion low impact messaging.

Limitations and strengths

This study focuses on trail use behaviour and trail design in a specific region in Far North Queensland, Australia. The results may not be generalisable to all outdoor recreation areas due to context-specific features. However, most of the elements used in this study are representative of current trail design and building guidelines, and this study is a starting point in the consideration of how trail design influences trail user behaviour. The study used a non-invasive approach to observe trail sites over twelve months, with photos taken from approximately the same positions at each observation point.

Recommendations

The results of this observational study provide essential insights for park managers. Based on the results, some key recommendations for the trail design are included for future multi-use trails:

1. Ensure sufficient site hardenings are used on steep sections of trails where trail users are creating significant trail spread.
2. Avoid the use of log features where they are likely to be compromised from fire damage, where planned fire management burns are used by park management.
3. Reduce shortcuts by walkers by using cairns, scree, or the provision of steps where appropriate.
4. On mountain bike trails, avoid soft surfaces above technical features where there is no-line-of sight, e.g., drops should include additional armouring or ways to reduce speed above the technical feature.
5. Provide sufficient, well-placed access to outdoor recreation facilities such as sanitation (flush/drop toilets).

Conclusion

This study provided an innovative approach to monitor the impacts of trail user behaviour over time. The study used current trail design and building guidelines to provide a practical application to this research to improve future trail design guidelines. GPS mapping of trail features, with photographic monitoring, can provide useful information to enhance the monitoring of current trail infrastructure, while providing an opportunity for improving future trail design and ultimately to reduce the environmental impacts of trail users. There is an increasing demand for outdoor recreation and park managers need to ensure that trail designs enhance opportunities for responsible tourism approaches by encouraging low impact outdoor recreation. This study found multi-use trail design needs to consider the different walker and mountain bike behaviours.

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