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ORIGINAL PAPER

Effects of trampling on in-stream macroinvertebrate communities from canyoning activity in the Greater Blue Mountains World Heritage Area

Nigel Hardiman · Shelley Burgin

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Abstract Perceived growth in the adventure recreation sport of canyoning in the Greater Blue Mountains World Heritage Area (Australia) has raised concerns with park management that such activity is resulting in unsustainable visitor impacts to canyon ecosystems. Three levels of trampling intensity were applied within an upland section of a canyon stream to assess the impact of trampling on benthic macroinvertebrate communities. After an initial detrimental effect from trampling, there was a rapid recovery of the macroinvertebrate community. Recovery occurred within one day of trampling ceasing, and overall community composition was similar among treatments after 15 days. However, by day 15 the untrampled sites showed a substantial decrease in animal abundance. This indicated that adjacent habitat contributed greatly to the recolonisation of animals into trampled areas.

Keywords Ecosystem disturbance · Canyons · Tourism impact · Nature-based tourism · Upland streams · Recreational impacts · Adventure recreation

N. Hardiman · S. Burgin (✉)
College of Health and Science, University of Western Sydney, South Penrith Distribution Centre, Locked Bag 1797, Sydney, NSW 1797, Australia
e-mail: s.burgin@uws.edu.au

Introduction

Although previous studies have been undertaken to investigate trampling in habitats favoured by tourists (e.g., coral reefs Liddle and Kay 1987; Kay and Liddle 1989; rock shores Beauchamp and Gowing 1982; Brosnan and Crumrine 1994; Ghazanshahi et al. 1983; Keough and Quinn 1998; Pickering and Hill 2007; Povey and Keough 1991; Schiel and Taylor 1999), freshwater habitats have received comparatively less attention (Liddle and Scorgie 1980; Rees and Tivy 1987; Ross 2006), and the impact of adventure tourism on upland streams has not been addressed.

Adventure recreation, defined as "outdoor activities in which the uncontrollable hazards of a natural environment or feature are deliberately challenged through the application of specially developed skills and judgment" (Brown 1989, pp. 37), has sustained strong growth over the last decade and is an important segment of the tourism market (World Travel and Tourism Council 2006). In parallel with its increasing popularity, adventure recreation has also been increasingly criticized for the associated environmental degradation (e.g., placement of permanent anchor bolts, vegetation loss, erosion; Ewert and Hollenhorst, 1997). The shift in emphasis by park management to the impacts of adventure recreation in the Greater Blue Mountains World Heritage Area west of Sydney is indicative of the evolving concern for the impact of such activities on natural areas. This change in emphasis may be demonstrated by a comparison between the 1988 Blue Mountains National Park Draft Plan of Management (NPWS 1988), which makes negligible mention of adventure recreation, and the 2001 Plan of Management (NPWS 2001) which includes extensive discussion of such activities with proposals for major changes in park management policy to combat the detrimental impacts emanating from canyoning. In the narrow slot valleys where canyoning is practiced, human disturbance is restricted to wading, swimming and abseiling within the stream.

There is a paucity of data on the environmental impacts of adventure recreation (Buckley 2005), and particularly the impacts on in-stream fauna due to the disturbance of visitors trampling. Previous research associated with coastal intertidal ecosystems (e.g., Rocky shores—Povey and Keough 1991; Keough and Quinn 1998; Mangrove forest—Ross 2006) has demonstrated that trampling can cause detrimental impacts on benthic macroinvertebrate communities that may take multiple years to dissipate (e.g., Ross 2006). In contrast, freshwater ecosystems (e.g., Reice 1985; Lake et al. 1989; Brooks and Boulton 1991; Matthaei et al. 1996) tend to recover rapidly from physical damage. However, previous studies have tended to be of short duration and mimic pulse events. There is some evidence (e.g., Reice 1985) that repeated disturbance reduces the rate of recovery, however, data appear to be lacking on the response of freshwater macroinvertebrates to sustained, season-long trampling pulse impact experienced by the most popular of the Blue Mountains canyons.

Since the only physical human impact on the canyons of the Blue Mountains is canyoning, these visitors provide a unique opportunity to investigate the impact of trampling on such upland streams as a basis for their sustainable management. In this paper we investigated the response of freshwater benthic macroinvertebrates to a pulse event approximately equivalent to the impact of streambed trampling by canyoners. The outcomes will provide information to support decisions to underpin the sustainable management of upland streams. The hypothesis we tested was that there was no significant impact on the macroinvertebrate community due to a trampling pulse event.

Methods

Study site

The project was undertaken in the Greater Blue Mountains World Heritage Area, Australia, located 50 km west of the country's largest city, Sydney (Fig. 1). This area is geologically underlain by soft, easily erodible Burra Moko Head sandstone of the Triassic Narrabeen group (Department of Mines 1966), and the dominant vegetation is sandstone plateau forest dry sclerophyll vegetation, typified by *Eucalyptus sieberi* and *Eucalyptus piperita* (National Herbarium 1977).

Although the exact number is unknown, there are over 400 canyons identified in the Area. These canyons have been formed by the erosive action of streams in the Plateau. They are typically deeply incised, with effectively vertical walls that have created narrow and dark, usually water-filled passages (often less than 1 m wide) between sheer rock walls (Jamieson 2001). Located within a World Heritage

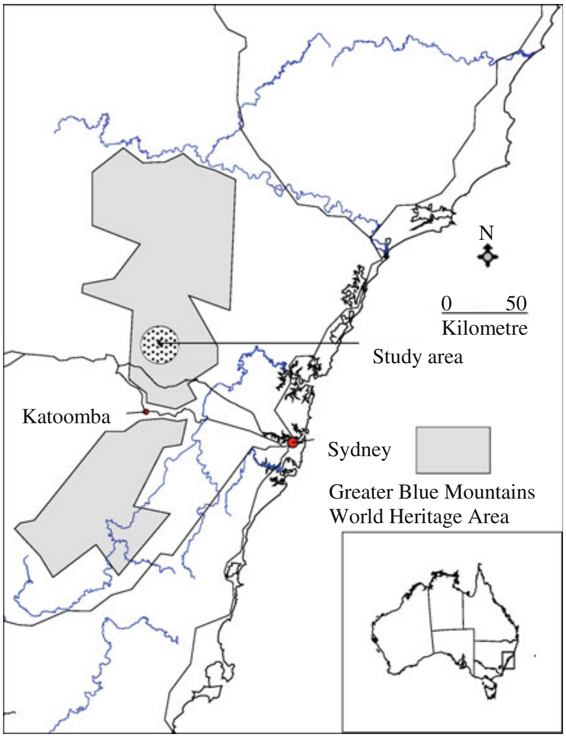


Fig. 1 Location of the study area in relation to the Greater Blue Mountains World Heritage Area and major centres of population

Area, and distant from residential or industrial development, or even urban dwellings, the canyons are separated from agricultural land by a buffer of native bushland. Access is only possible by walking on (at best) poorly defined tracks, usually over many kilometres. The only direct anthropogenic impact on the canyon ecosystems is the trampling of canyoners as they move through the canyons.

Within this area, the trampling simulation was performed in a pristine wilderness upstream section of Bell Creek, a 4th order stream (cf. Strahler 1957) at altitude 810 m above sea level (33°30′S, 150°20′N; map reference 516897, Central Mapping Authority of New South Wales, topographic map 1:25,000 scale, Sheet 8930-1-N Mount Wilson). The site is typical of upland canyon streams of the area. The sampling was undertaken along an 80 m riffle zone with a cobble/pebble substratum with an average depth of approximately 30 cm, measured at 5 m intervals along a longitudinal transect through the deepest section of the channel.

Experimental design, site layout and sampling procedure

The experiment was established with the following factors:

1. Recovery period: three levels (1, 15, 27 days).
2. Plots: three levels (three separate blocks).
3. Trampling intensity: three levels (0, 50, 100 tramples per day, for seven consecutive days).

The sampling unit was a wire quadrat (1 m^2), with $n = 3$ replicate quadrats for each Recovery Period × Trampling Intensity combination (Fig. 2). The experiment was a split-plot design, as described by Snedecor and Cochran (1989) and Underwood (1997), p 398 and Table 12.5).

To achieve complete independence between treatments, separate sites would ideally have been arranged in separate streams but this was not possible due to time and geographical constraints. Three blocks of riffle zone, each having a cobble/pebble substratum and average depth of approximately 30 cm, measured at 5 m intervals along a longitudinal transect through the deepest section of the channel, were therefore arranged in linear fashion down a single stream, i.e., Bell Creek. Owing to the very narrow canyon channel, a maximum of two quadrats could be placed across the stream, a uniform 1 m apart.

Owing to such limitations, plus the fundamental element of longitudinal water flow downstream, there was a possibility of non-independence caused by sediment drift and/or washing down of animals through the site. Such potential for non-independence was recognized and managed by the following:

(i) Physical separation of each riffle zone by a minimum 10 m stretch of very shallow riffle (<15 cm)/dry zone;
(ii) Randomisation of position of trampling intensity quadrats within plots;
(iii) Randomisation of recovery period plots within blocks; and
(iv) Collection of all animals in an upstream direction.

The 1 m^2 wire quadrats were installed on the streambed on 11th Nov 2000, with small wire hoop pegs and left to colonise for 9 days. Trampling was then performed daily during 20–26th Nov, followed by sampling on 27th Nov (1 day recovery), 11th Dec (15 days recovery) and 23rd Dec (27 days recovery).

A "trample" consisted of an experienced canyoner (the senior author), wearing rubber-soled Dunlop "volley" shoes (Dunlop Rubber, Sydney) of the type favoured by canyoners, walking longitudinally upstream across a quadrat, pivoting outside and re-crossing it downstream, repeating to the desired trampling intensity. The aim was to mimic typical walking action of a canyoner in disturbing the substratum; therefore, no grinding or deliberate overturning of cobbles occurred. All trampling was undertaken starting from the most downstream quadrat, and moving upstream to the most upstream quadrat.

Due to the imperative of completing each sampling episode within a single day because of the remoteness of the area, and the lack of dry space to camp within the canyon, a rapid technique was required. Several procedures for rapid assessment using macroinvertebrates have been developed, especially in the United States (reviewed by Resh and Jackson 1993). However, many of these involve relatively heavy/bulky equipment (e.g., Surber Sampler) which is not suitable for sampling sites in rugged, remote terrain where the only access is on foot (often without formed tracks) and transported

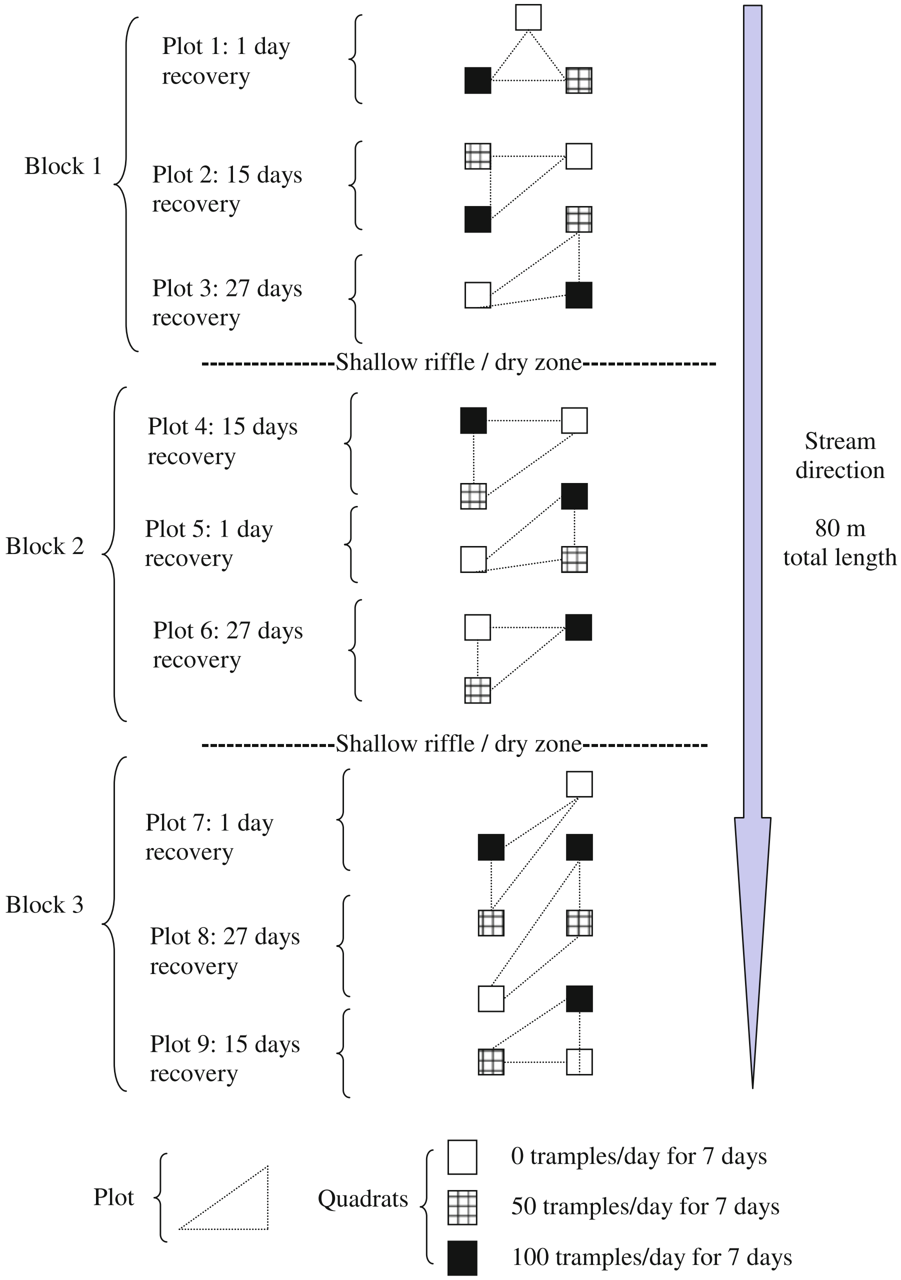


Fig. 2 Physical layout of trampling experiment in Bell Creek

while swimming and abseiling down waterfalls. The sampling procedure and equipment therefore needed to (i) be simple, small, robust and light, and transportable even to remote sites; (ii) allow for picking of specimens to be done in the field by non-specialist personnel; and (iii) minimise the amount of material to be transported to the laboratory. Our procedures followed the development of techniques of previous researchers (Chessman 1995; Growns et al. 1995) working under equivalent conditions except that we standardised on time and not number of invertebrates. This was because the sampling environment is harsh and hypothermia for field personnel is a real safety issue.

Collection of invertebrates consisted of a 2 min shuffle and kick of the substratum within each quadrat while holding a kick net (250 μm mesh, mouth opening of 30 × 25 cm) downstream and vertically into the current with the net mouth in contact with the substratum. Each quadrat was sampled only once during the study and then removed. Animals collected were then emptied into a plastic sorting tray and picked for 5 min, followed by four random grabs (eyes closed) with narrow-nosed tweezers to collect representative samples of debris which may have contained small and/or cryptic invertebrates. Animals and debris were then stored in a 5% formaldehyde solution in 50 ml plastic jars for transport to the laboratory where they were sorted for 30 min and identified to order and family (cf. Hardiman and Burgin 2010a).

Data analysis

Data were analysed using both multivariate and univariate analysis. Multivariate analyses were made using the PRIMER v5 software package. Non-metric multidimensional scaling (NMDS) was performed on the (rank) similarity matrices of associations between all pairs of sample collections, computed using the Bray-Curtis similarity coefficient (Clarke 1993; Clarke and Warwick 1994) on the square root transformed data (Hardiman and Burgin 2010a). One-way analysis of similarities (ANOSIM), another non-parametric permutation procedure applied to the (rank) similarity matrix underlying the MDS ordination, was also employed at order and family taxonomic level to test for significance between "Intensity" and "Recovery Period".

Shannon-Wiener diversity and Simpson dominance analyses were conducted on the total number of individual animals (abundance), and total number of orders and families. As several replicates yielded ≤ 1 animal, calculation of diversity and dominance indices using raw abundance figures was impractical (due to the log transform involved in these indices' formulae). The integer one was added to each replicate in the data matrix to generate these two indices. The Student Newman Kuels test (SNK) was used to test for significant differences in univariate indices between individual trampling treatments within recovery periods.

Data were transformed if Cochran's test showed significant heterogeneity of variances. Indices were then analysed by a split-plot ANOVA, with Recovery Period (Fixed factor, three levels) and Plots (Random factor, three levels) as the between-subject factors, and Trampling Intensity (Fixed factor, three levels) as the within-subjects factor, using the STATISTICA software package. Error terms to the between- and within-subject terms were used as appropriate.

Results

Overview of macroinvertebrate community

A total of 207 animals from eight orders and 16 families were collected. Family richness was relatively evenly spread across orders: Coleoptera, Diptera and Plecoptera (three families each), while Ephemeroptera and Trichoptera were each represented by two families. A single family was collected from three other orders (Table 1).

Among orders, Ephemeroptera had the greatest abundance and comprised 60.9% of the total invertebrates collected, while the Diptera and Plecoptera each comprised 13.0% of the invertebrates collected. Most (81.7%) of the macroinvertebratres were concentrated in three families: Leptophlebiidae (Ephemeroptera; 59.4% of all invertebrates), Chironomidae (Diptera; 11.6%), and Notonemouridae (Plecoptera; 10.6%). None of the other 13 families collected contributed more than 6% to the total abundance.

Macroinvertebrate community recovery one day after trampling

One day after trampling ceased, NMDS analysis indicated a difference in macroinvertebrate community composition among the three trampling intensities at both order and family level (Fig. 3). The difference in community composition between untrampled and trampled quadrats was due to the reduced abundance of Ephemeroptera and a complete absence of Trichoptera in trampled quadrats. ANOSIM (Table 2) indicated that there was a significant difference at order level between the three treatments (Global $R = 0.52$, $P = 0.02$). Pairwise tests confirmed a difference ($P = 0.10$) among all three trampling intensities at order level, but only between untrampled sites and the highest trampling intensity at family level. Note: the data set was insufficiently large to allow a higher number of permutations and hence possible significance testing lower than 10%.

Compared to untrampled quadrats, the mean abundance was lower (71 and 79%, respectively) in

Table 1 Total number and percentage of macroinvertebrates at each taxonomic level collected from Bell Creek in November and December, 2000

Order	Abundance	%	Family	Abundance	%
Ephemeroptera	126	60.9	Leptophlebiidae	123	59.4
Diptera	27	13.0	Chironomidae	24	11.6
Plecoptera	27	13.0	Notonemouridae	22	10.6
Trichoptera	14	6.8	Ecnomidae	12	5.8
Coleoptera	7	3.4	Gripopterygidae	4	1.9
Neuroptera	4	1.9	Neurorthidae	4	1.9
Acarina	1	0.5	Psephenidae	4	1.9
Odonata	1	0.5	Oniscigastridae	3	1.5
Total	207	100.0	Elmidae	2	1.0
			Hydrobiosidae	2	1.0
			Tipulidae	2	1.0
			Ceratopogonidae	1	0.5
			Corduliidae	1	0.5
			Dytiscidae	1	0.5
			Eustheniidae	1	0.5
			Hygrobatidae	1	0.5
			Total	207	100.0

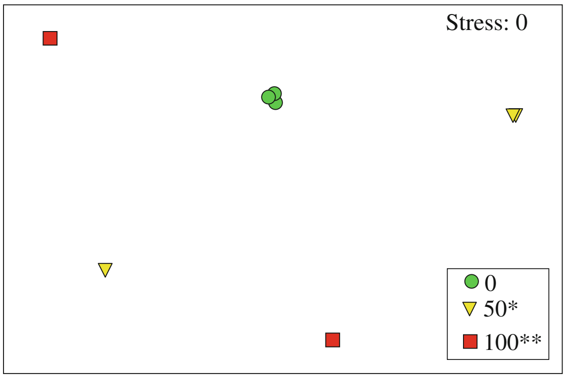
quadrats receiving 50 and 100 tramples/day. The mean order number was also reduced by 50% in areas trampled 50 times/day over a week (orders 83%), and the mean family number was reduced by 46% (50 tramples/day; 85%, 100 tramples/day). The ANOVA showed that only the "Recovery period" × "Trampling intensity" interaction was significant for animal abundance and order (Table 3). A post-hoc SNK test failed to identify where the significant differences lay.

Compared to untrampled quadrats, mean diversity at the order (32%) and family (30%) level was lower in quadrats trampled 50 times/day over a week compared with quadrats trampled 100 times/day (order, 73%; family, 74%). Although the mean diversity at each taxonomic level was substantially lower in the trampled sites (50 and 100 tramples/day for 1 week) compared to untrampled sites, post-hoc tests showed this was non-significant. There was also no significant difference among trampling treatments on mean dominance (Table 3).

Macroinvertebrate community recovery 15 days and 27 days after trampling

Fifteen days after trampling ceased, NMDS analysis indicated no difference in macroinvertebrate community composition among the three trampling intensities at both order and family level (Fig. 4). Community composition of trampled sites at both taxonomic levels showed recovery to similar levels of diversity by 15 days, and the macroinvertebrate community was at similar levels when last sampled after 27 days (i.e., non-significant ANOSIM Global and Pairwise R, Table 2). In contrast, abundance in untrampled sites dropped between days 1 and 15 post-trampling, and at 15 days the abundance in untrampled sites was substantially below those that had been trampled. Conversely, at 27 days the abundance in untrampled sites was substantially above the diversity in trampled sites (Fig. 5a). As with the pattern of abundance observed between trampled and untrampled sites, at the order (Fig. 5b) and family level (Fig. 5c) there were relatively fewer taxa in untrampled sites compared to trampled sites at 15 days post-trampling. However, at 27 days post-trampling, diversity was similar to initial samples taken 1 day post-trampling. Despite this, only the mean animal abundance for untrampled quadrats was significantly different between 1 and 27 days ($F = 9.08_{2,4}$, $P = 0.03$, Table 3). There was no significant difference in mean order or family diversity or dominance among treatments.

Order



Family

Fig. 3 Ordination of macroinvertebrate community at different trampling intensities (0, 50 or 100 tramples) after 1 day recovery from 7 days' trampling. *Symbols* denote daily trample intensity. * Two quadrats had identical fauna and are superimposed; ** one quadrat had zero fauna hence only two quadrats plotted. Data square root transformed

Discussion

Trampling in the narrow slot valley canyons of the Greater Blue Mountains World Heritage Area had an immediate detrimental effect (1 day recovery) on the community composition of resident macroinvertebrates at 50 tramples/day. There was a reduction in taxa in the trampled, compared to untrampled areas. This observation reflects the results of some previous, multiple frequency disturbances (e.g., Brooks and Boulton 1991; Lake et al. 1989, Matthaei et al. 1996; Reice 1984, 1985), and due to natural flood disturbances (Molles 1985).

The most substantial change in taxa observed was a reduction in the abundance of Ephemeroptera, and loss of Trichoptera from trampled areas. Within the upland streams of the area of this study, Wright and Burgin (2009) found that these taxa were similarly affected by pollution from treated sewage effluent and zinc-rich coal mine waste.

Previous Australian research on the impact of trampling on freshwater macroinvertebrates (e.g., Brooks and Boulton 1991; Lake et al. 1989; Matthaei et al. 1996) showed that macroinvertebrate recovery occurred at between 4 and 33 days. However, the impacts were longer term than we observed. The impact of trampling has also been shown to be more sustained in intertidal areas. For example, in a temperate mangrove forest, Ross (2006) observed that species were impacted at much lower trampling intensity than we inflicted on the canyon environment. We observed that by day 15 after trampling at 50 and 100 tramples/daily for 1 week (much higher trampling intensity than some of the previous studies, e.g., Ross 2006), the community showed recovery.

The lack of difference in diversity and dominance, even 1 day after trampling ceased suggests a common response to the disturbance across most taxa as observed in some previous studies of multiple frequency disturbance (e.g., Lake et al. 1989; Reice 1984). For example, even species acknowledged to be sensitive to disturbance (e.g., Ephemeropthera, Trichoptera) and initially disseminated by trampling, had recolonised plots 2 weeks later. In contrast, impacts on invertebrate taxa in the intertidal zone have been shown to persist for at least 2 years after relatively low trampling intensity (e.g., Collier and Quinn 2003; Ross 2006).

Our results revealed that although the canyon macroinvertebrate community composition (order and family) was impacted by trampling, recovery was rapid, even at the highest levels of trampling. Although the frequency of trampling used was substantially greater than in some studies (e.g., Brooks and Boulton 1991; Lake et al. 1989; Matthaei et al. 1996; Reice 1985; Ross 2006), the most popular canyons in the Greater Blue Mountains World Heritage Area (e.g., Claustral Main, Hardiman and Burgin 2009) have higher visitation levels during the canyon season (September–April). Despite this level of impact, Hardiman and Burgin (2010a) observed that macroinvertebrate abundance and diversity in canyons were not substantially different due to differing levels of recreational trampling. This supports the observation that, after disturbance,

Table 2 Analysis of similarities between Bell Creek trampling treatments after 1, 15 and 27 days recovery from 7 days trampling

Source	Order		Family	
	Test	Significance	Test	Significance
1 Day recovery	Global R	*P*	Global R	*P*
All tramples	0.52	0.02	0.29	0.12
Pairwise comparison	Pairwise R	*P*	Pairwise R	*P*
0 and 50 tramples	0.67	0.10	0.33	0.20
0 and 100 tramples	0.54	0.10	0.63	0.10
50 and 100 tramples	0.58	0.10	0.00	0.40
15 Days recovery	Global R	*P*	Global R	*P*
All tramples	−0.10	0.68	−0.25	0.87
Pairwise comparison	Pairwise R	*P*	Pairwise R	*P*
0 and 50 tramples	−0.08	0.70	−0.42	0.90
0 and 100 tramples	0.00	0.50	0.00	0.50
50 and 100 tramples	−0.19	1.00	−0.41	1.00
27 Days recovery	Global R	*P*	Global R	*P*
All tramples	0.05	0.43	−0.00	0.55
Pairwise comparison	Pairwise R	*P*	Pairwise R	*P*
0 and 50 tramples	0.19	0.40	0.04	0.60
0 and 100 tramples	0.11	0.30	0.15	0.50
50 and 100 tramples	−0.11	0.80	−0.15	0.80

Data square root transformed. *Note* the data set was insufficiently large to allow higher number of permutations and pairwise significance testing lower than 10%. R values lie within the range (−1 and 1). R = 1 if all replicates within treatments are more similar to each other than any replicates from different sites; R is approximately zero if similarities between and within treatments are the same (Clarke 1993; Clarke and Warwick 1994)

recolonisation occurs rapidly among the invertebrates of these canyons, despite the dominance of sensitive taxa (e.g., leptophlebiids).

Brooks and Boulton (1991) suggested caution is required in the extrapolation of results on recolonisation due to physical disturbance based on small plots to large-scale disturbance. This is because the scale of disturbance may influence the rate and pathway of recolonisation, together with the source and faunal composition of the colonists. The rapid recovery from trampling that we observed may have been facilitated by the small size of the plots. This is supported by the observation that while trampled sites had recovered to pre-trampling levels 15 days after trampling ceased, the untrampled sites had lower macroinvertebrate numbers than trampled plots. Our interpretation of these results is that the invertebrates from untrampled areas in the canyon supported the recovery of trampled areas. By 1 month after trampling ceased, the untrampled areas also showed recovery, indicating that the whole ripple zone had recovered to pre-trampling levels. This could be interpreted as recolonisation from elsewhere within the stream.

Most of the taxa present in the canyons are the larvae of arthropods, many of which breed opportunistically year around. For example, Hardiman and Burgin (2010a) found leptophlebiids in all instars, in all seasons over the 2 years they sampled. This indicated that colonisation is aseasonal. For at least some species, this presents a further opportunity to support recovery from perturbation. Hardiman and Burgin (2010a) also reported that the community integrity was maintained over time, despite major disturbance during the canyon season that has been sustained over many years. Our results therefore indicate that, at least in the "pristine streams" of the canyon environment we studied, the macroinvertebrate community was able to persist even in the presence of high levels of trampling.

Conclusion

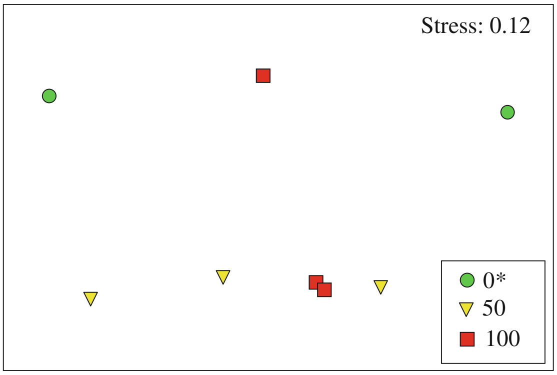
Park management considers the canyon ecosystems of the Blue Mountains to be "fragile" and at risk of degradation from canyoning adventure recreation, although the level of such visitation and the nature and degree of such potential biological fragility are not defined nor underpinned by scientific evidence. This has led management to make policy on the basis of the "precautionary principle", i.e., assume an activity to be harmful until shown otherwise.

Table 3 Three factor analysis of variance of mean animal abundance, order and family 1, 15 and 27 days post-trampling for 1 week at 0, 50 and 100 tramples/day for 1 week

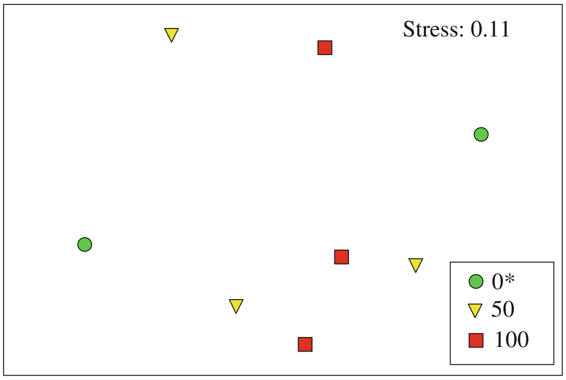
Source	*SS*	*df*	*MS*	*F*	*P*	*F*-test vs
Animal abundance						
R: Recovery period	242.00	2	121.00	9.08	0.03*	Main plot error
P: Plots	50.00	2	25.00	1.88	ns	Main plot error
Main plot error (R × P)	53.32	4	13.33			
T: Trampling intensity	28.66	2	14.33	0.65	ns	Subplot error
R × T	287.32	4	71.83	3.26	0.05*	Subplot error
Subplot error (P × T) + (R × P × T)	264.68	12	22.06			
Total	925.98	26	35.61			
Order						
R: Recovery period	5.86	2	2.93	1.72	ns	Main plot error
P: Plots	4.74	2	2.37	1.39	ns	Main plot error
Main plot error (R × P)	6.80	4	1.70			
T: Trampling intensity	5.86	2	2.93	2.05	ns	Subplot error
R × T	25.04	4	6.26	4.39	<0.025*	Subplot error
Subplot error (P × T) + (R × P × T)	17.12	12	1.43			
Total	65.42	26	2.52			
Family						
R: Recovery period	6.22	2	3.11	1.81	ns	Main plot error
P: Plots	6.22	2	3.11	1.81	ns	Main plot error
Main plot error (R × P)	6.88	4	1.72			
T: Trampling intensity	8.22	2	4.11	2.22	ns	Subplot error
R × T	32.88	4	8.22	4.44	<0.025*	Subplot error
Subplot error (P × T) + (R × P × T)	22.24	12	1.85			
Total	82.66	26	3.18			

Data untransformed,
* significant at 5% or less,
ns not significant

Lacking objective data, management has in the past relied on anecdotal data, believing that (i) levels of canyoning along accessible sections of the canyons are "high" and are continuing to increase; (ii) the "majority" of visitation is made by commercial canyon tour operators; (iii) canyoning is spread over "many" sites and (iv) unsustainable biological impact ensues. This has led to policy being adopted that limits both size of parties and number of trips made by commercial operators to a small number of designated sites, plus physical closure of or increased difficulty of access to many other sites. Hardiman and Burgin (2010b) were able to demonstrate that the converse of such anecdotal belief is in fact true, i.e., that (i) overall visitation is lower than perceived and probably declining, (ii) the majority of visitation is made by independent, non-commercial groups of friends (and hence not controllable), and



Order



Family

Fig. 4 Ordination of macroinvertebrate community at different trampling intensities (0, 50 or 100 tramples) after 15 days recovery from 7 days' trampling. *Symbols* denote daily trample intensity. * One quadrat had zero fauna hence only two quadrats plotted. Data square root transformed

(iii) visitation is not widely dispersed but is highly concentrated in a very small number of sites. In a second phase of research, Hardiman and Burgin (2010a) were able to demonstrate that there was no statistical difference in macroinvertebrate communities between canyon sites subject to (relatively quantified) high and low visitation over many years. This final, third phase of research now demonstrates that even in a pristine canyon exposed to a frequency and intensity of visitation substantially higher than that actually experienced by any known canyon site, the macroinvertebrate community—a known critical bioindicator of ecosystem health—is apparently sufficiently adapted to natural physical disturbance that such visitation is sustainable, at least at the levels tested. This finding, therefore, has important implications for park management regarding balancing and meeting its twin strategic objectives of recreation and conservation.

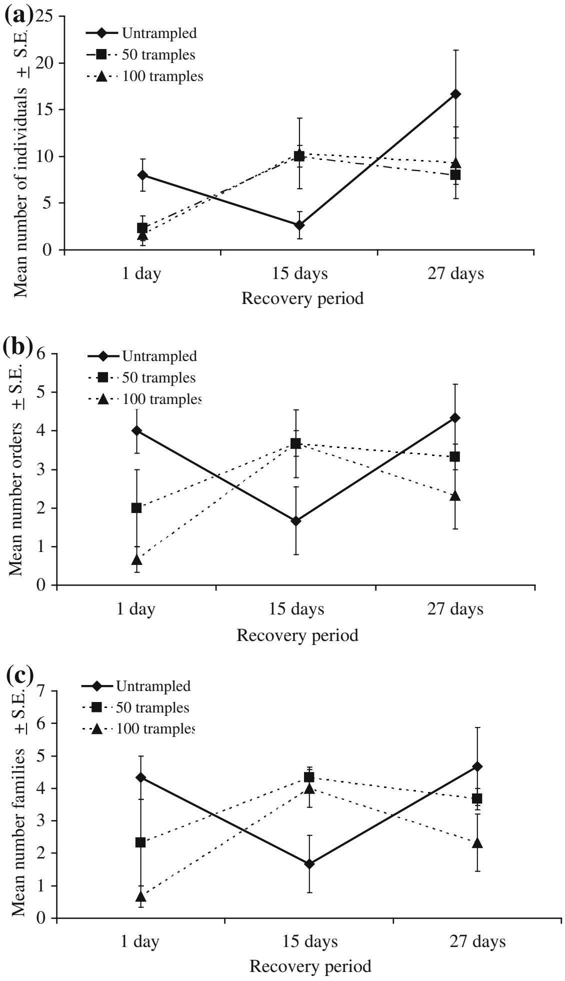


Fig. 5 Mean number ± S.E. for **a** animal abundance; **b** order, and **c** family after 1, 15 and 27 days recovery from 7 days trampling. Data untransformed

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