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ORIGINAL PAPER

Recreational trampling negatively impacts vegetation structure of an Australian biodiversity hotspot

S. Mason[1] · D. Newsome[1] · S. Moore[1] ·
R. Admiraal[2]

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Abstract Recreational trampling damage of natural vegetation is an increasing problem in the global context and has the potential to impact on vegetation communities that are of high ecological and socio-economic interest. Wildflower tourism in the national parks of southwest Australia, a global biodiversity hotspot, has the potential to damage the flora on which it depends through trampling. Little research has been previously undertaken in these largely shrub-dominated communities to identify and quantify such impacts. This study is the first to do so, using observational studies of tourists, a descriptive study, and trampling experiments. The behaviours of independent tourists and tour groups were observed. Of the 213 independent visitors observed 41 visitors left trails to view flowers and in the process trampled vegetation. Vegetation height and cover were measured at three sites frequented by wildflower tourists. Vegetation height and cover declined in response to use by tourists. Trampling experiments, which relied on trampling treatments of 0, 30, 100, 200, 300/500 passes, where 0 passes represents the control, were applied at four sites. Trampling led to a significant reduction in vegetation height immediately post-treatment, for all treatments, with a non-significant recovery over time. Trampling also significantly reduced vegetation cover, with the resistance indices for these experimental sites ranging from 30 to 300 passes. Collectively these results illustrate the low resilience and resistance of these valued communities and the possible impacts of wildflower and other nature based tourism, through trampling. The paper concludes with suggested

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✉ D. Newsome
d.newsome@murdoch.edu.au

1 Environment and Conservation Sciences Group, School of Veterinary and Life Sciences, Murdoch University, Perth, WA, Australia

2 Mathematics and Statistics Group, School of Engineering and Information Technology, Murdoch University, Perth, WA, Australia

management strategies, which strongly emphasise the importance of education for the tourism industry and provide for international comparisons in regard to recreational trampling impacts on biodiverse shrub land communities.

Keywords Wildflower tourism · Trampling · Resistance · Resilience · Biodiversity hotspot

Introduction

Trampling is one of the most visible forms of disturbance to vegetation as a result of recreational use resulting in loss of vegetation height and cover, damage to soils and changes in plant community composition (Kelly et al. 2003; Cole 2004; Hill and Pickering 2006; Pickering and Hill 2007; Monz et al. 2010a, b; Ballantyne and Pickering 2013; Newsome et al. 2013). Trampling of vegetation and soils can occur when recreational users leave an established trail to take a photograph, investigate a flower or create an informal trail for their own purpose (Pickering and Hill 2007; Ballantyne and Pickering 2012; Barros et al. 2013; Newsome et al. 2013). Knowledge about the relationship between the effects of trampling and the sensitivity of vegetation is essential in effectively managing these interactions (Liddle 1997; Cole 2004; Hamberg et al. 2010; Pickering et al. 2010). Moreover, understanding this relationship is particularly important in areas of high conservation value (Hopper and Gioia 2004; Pickering and Hill 2007; Hopper 2009; Sloan et al. 2014).

Southwest Australia (SWA) is a global biodiversity hotspot with high conservation values and serves as an example of globally significant flora that are currently under stress from a range of threatening processes (Myers et al. 2000; Sloan et al. 2014). Australian flora are particularly vulnerable to anthropogenic change due to high levels of diversity and endemism, with many species in Western Australia exhibiting small ranges with low numbers and restricted populations (Hopper 1979; Hnatiuk and Hopkins 1981; Hopkins et al. 1983; Pate and Beard 1984; Burbidge et al. 1990; Hopper and Gioia 2004). The SWA global biodiversity hotspot is also a global destination for wildflower tourism and national parks in SWA attract thousands of visitors each year to experience the 'show' of wild flowers (Burbidge et al. 1990; CALM 1991, 1995, 1999; Agafonoff et al. 1998; TWA 2005, 2011).

There have been many experimental and descriptive studies worldwide that have examined the impacts of trampling on vegetation and soils (Cole 1987; Liddle 1997; Leung and Marion 2000; Buckley 2005; Pickering and Hill 2007; Malmivaara-Lamsa et al. 2008; Torn et al. 2009; Barros et al. 2013; Barros and Pickering 2014; Prescott and Stewart 2014). Trampling studies conducted in North America and Europe have examined a range of vegetation types, from beech forest (Waltert et al. 2002) to arctic tundra plant communities (Monz 2002).

Australian studies have centered on trampling in mountain, subtropical and tropical areas (Whinam and Chilcott 1999; Talbot et al. 2003; Whinam and Chilcott 2003; Hill and Pickering 2009; Pickering and Growcock 2009). Kelly et al. (2003) considered the direct and indirect effects of tourism on 72 plant taxa in Australia by reviewing literature and reports by government agencies. Trampling was identified as the most common impact affecting 20 plant taxa. Ballantyne and Pickering (2012) have recently reported that orchids are directly affected by human trampling of their habitats.

Liddle (1997) and other researchers have demonstrated that different vegetation communities respond to trampling according to differing environmental conditions, plant functional traits and varying types of user and use intensities (Liddle 1975, 1997; Cole 1985; Pickering et al. 2010; Bernhardt-Romermann et al. 2011; Monz et al. 2013; Prescott and Stewart 2014). The available evidence points to shrubs with sclerophyllous tissues being one of the most susceptible plant communities to trampling damage (for example see, Sun and Liddle 1993a; Liddle 1997; Newsome et al. 2002; Whinam and Chilcott 2003; Pickering and Hill 2007; Bernhardt-Romermann et al. 2011). Data on resistance (plant response to damage) and resilience (recovery of vegetation from disturbance) is especially lacking for sclerophyllous shrub-dominated plant communities in Australia.

Virtually no published data exist regarding how shrub-dominated vegetation has been impacted by, and responded to tourism and recreation, in national parks that form the centrepiece of the SWA biodiversity hotspot. Accordingly, there is an urgent need to add information on the effects of recreation and tourism on such plant communities (Kelly et al. 2003; Whinam and Chilcott 2003; Pickering et al. 2010) to the global store of knowledge on biodiversity hotspots. Accordingly, the objectives of this paper are threefold: (1) to provide observational data on the visitors to these national parks; (2) conduct descriptive studies at these parks on the trampling impact of visitors during the wildflower season; and (3) conduct controlled trampling experiments at these parks and report on the response of vegetation. These objectives are explored through observational, descriptive and experimental studies described in detail in the remainder of the paper.

Methodology

Rationale for park and site selection

Important protected areas and sites of high biodiversity and endemism in SWA include the Stirling Range National Park (SRNP), Fitzgerald River National Park (FRNP) and Lesueur National Park (LNP) (Fig. 1). All three have been identified as the most significant areas for flora conservation in SWA, with high species diversity (Gole 2006).

Within LNP and FRNP, two research locations were selected, with one location only in SRNP due to access restrictions. For each location a research site was allocated to descriptive studies and the other to experimental trampling. This gave a total of 10 research sites (Table 1). All locations and sites were selected in consultation with the park management agency staff, with initial selection ensuring locations that are accessed for wildflower tourism.

Park descriptions

The three national parks contain hyperdiverse shrublands where in a single plot of 10 m × 10 m (0.01 ha) there may be as many as 40 shrub species occurring as mature individuals (Laliberte et al. 2014). Lesueur National Park (26,987 ha) contains 821 different plant species, 111 are endemic to the area (LNP, Fig. 2a; Table 1) (CALM 1995). Stirling Range National Park (115,920 ha) contains 1748 species, 75 of which are endemic (SRNP, Fig. 2b; Table 1) (CALM 1999). Fitzgerald River National Park (329,039 ha) has

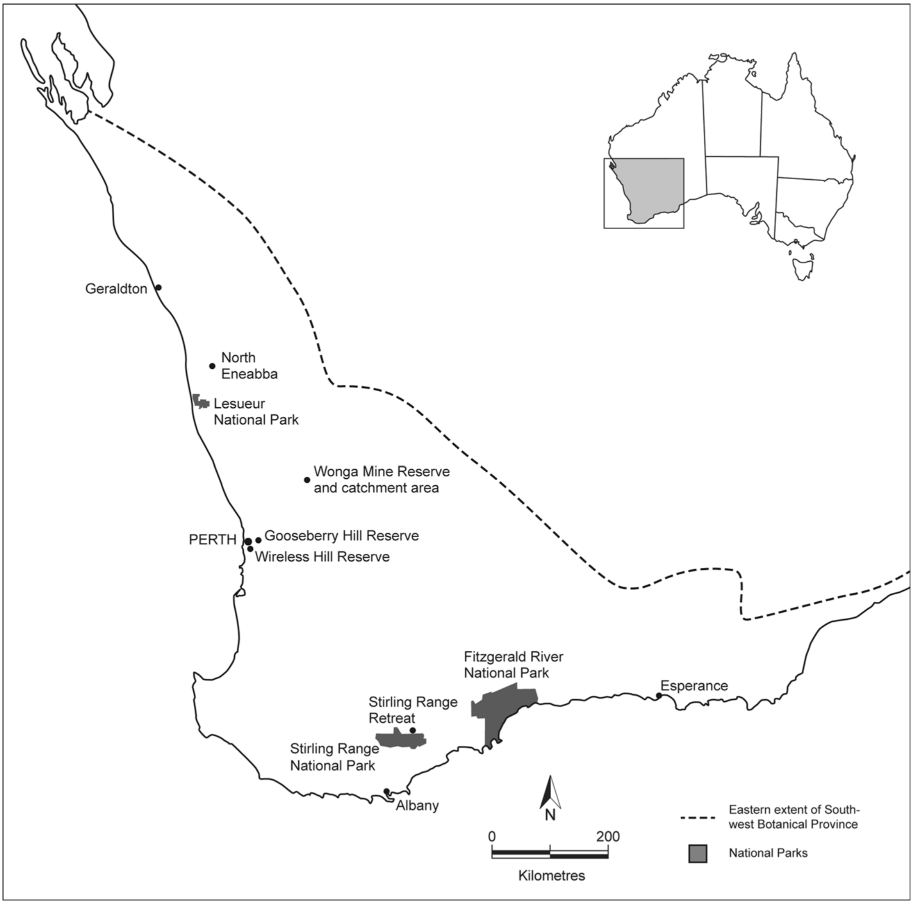

Fig. 1 Protected areas that exhibit high endemism and form core components of the Western Australian international biodiversity hotspot

1530 species with 82 endemics (FRNP, Fig. 2c; Table 1) (CALM 1991). Vegetation communities within the parks are dominated by shrubs, significant genera are *Hakea*, *Acacia*, *Banksia*, *Melaleuca*, *Leucopogon* and *Verticordia* (Table 2). Plant characteristics comprise shrub life-forms, erect plants, with woody stems and are typically slow growing (Table 2).

The wildflower season in Western Australia generally starts in June in the North (around LNP) and finishes in the South (around FRNP and SRNP) in November (TWA 2011). These three national parks play an important role in the wildflower tourism industry.

Observations of the visitors to the national parks (study one)

In order to determine the effects of visitors on the vegetation of the national parks participant observation of tourists to the three national parks was conducted during the wildflower season (Denscombe 1998; Jennings 2010). Observations focused on the behaviours of independent travellers and those on organised wildflower tours. These observations were conducted to determine if visitors went off trail and trampled the

Table 1 Sites selected for descriptive and trampling experiment studies

National park	Site	Plant community	Typical genera[a]
Lesueur National Park: 821 species (111 endemic); visitation (2013–2014) 11,655	LD3: Lesueur Day Use Area LE1: Near Lesueur Day Use Area	Dominated by shrubs	*Hakea*, *Acacia*, *Eucalyptus*, *Melaleuca*, *Grevillea*, *Daviesia*, *Darwinia*, *Thysanotus*, *Tetratheca*, *Petrophile*
	LD4: Information Bay LE2: Near Information Bay	Dominated by shrubs	*Astroloma*, *Leucopogon*, *Cryptandra*, *Daviesia*, *Gastrolobium*, *Synaphea*, *Lechenaultia*, *Olearia*, *Leptospermum*, *Lomandra*
Fitzgerald River National Park: 1530 species (82 endemic); visitation (2013–2014) 63,417	FD3: East Mt Barren Carpark 1 (burnt in wildfire, not used) FE1: Near East Mt Barren Carpark 1	Dominated by shrubs	*Eucalyptus*, *Banksia*, *Acacia*, *Calothamnus*, *Stylidium*, *Leucopogon*, *Hakea*, *Melaleuca*, *Verticordia*, *Schoenus*
	FD4: East Mt Barren Carpark 2 (burnt in wildfire, not used) FE2: Near East Mt Barren Carpark 2 (burnt in wildfire, not used)	Dominated by shrubs	*Eucalyptus*, *Leucopogon*, *Banksia*, *Jacksonia*, *Adenanthos*, *Calothamnus*, *Lasiopetalum*, *Sphenotoma*, *Hibbertia*, *Acacia*
Stirling Range National Park: 1748 species (75 endemic); visitation (2013–2014) 68,365	SD2: Pay Station at Bluff Knoll SE1: South of Papercollar Bridge	Dominated by shrubs	*Acacia*, *Hakea*, *Stylidium*, *Banksia*, *Kunzea*, *Petrophile*, *Astroloma*, *Leucopogon*, *Melaleuca*, *Verticordia*

Sources CALM (1991, 1995, 1999), Thomson et al. (1993), Newbey (1995), Paczkowska and Chapman (2000), Smith (2014)

[a] Recorded genera from NatureMap website: http://naturemap.dec.wa.gov.au

vegetation. Independent travellers were observed at sites within the three national parks (Fig. 2a–c). The sites visited by wildflower tourists were selected in consultation with park management agency staff. An unobtrusive observer at each site recorded a range of variables. The variable relevant to this paper was if the visitor stayed on formal trails or went off the trails into the vegetation.

The lead author observed the behaviour of tourists on four organised wildflower tours as an anonymous participant. Due to the availability of tours at the time, these tours did not necessarily visit the three national parks that form the basis of this study but they did visit protected areas in SWA and hence provide a snapshot of tour guide and visitor activity in this region. Tour duration ranged from 3 to 10 hours (mean 6 hours) and tour numbers ranged from 12 to 38 visitors (mean 19 visitors). The researcher observed visitor behaviour in regards to leaving walking trails and in relation to supervision and information provided by the tour guides.

Descriptive studies (study two)

The before mentioned preliminary observational studies were followed by a detailed descriptive study using the comparison of used and unused wildflower visitation sites to

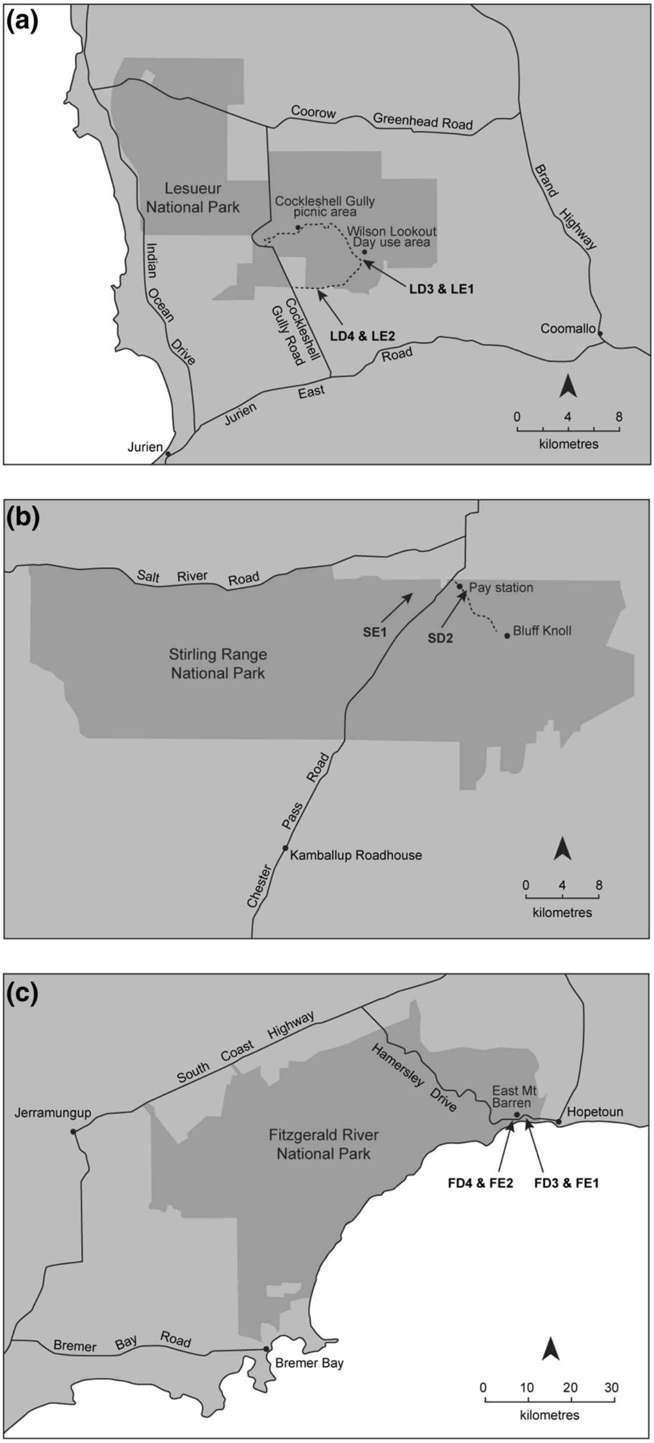

Fig. 2 Study area locations within the national parks

Table 2 Morphological, anatomical and physiological characteristics of plant genera dominating the vegetation community at LNP, FRNP and SRNP study sites

Genus present and dominant at study sites				Plant characteristics			
Plant genus	LNP	FRNP	SRNP	Shrub life form (morphological)	Erect plant (morphological)	Woody stem (anatomical)	Slow growing (physiological)
Hakea	√	√	√	√	√	√	√
Acacia	√	√	√	√	√	√	√
Eucalyptus	√	√	×	√	√	√	√
Melaleuca	√	√	√	√	√	√	√
Leucopogon	√	√	√	√	√	√	√
Banksia	×	√	√	√	√	√	√
Stylidium	×	√	√	× (herb)	√	×	√
Verticordia	×	√	√	√	√	√	√

Sources Beard (1990), Paczkowska and Chapman (2000), Hopper and Gioia (2004), http://florabase.dpaw.wa.gov.au; Accessed 03/03/14

determine if visitors had a trampling impact on vegetation over the wildflower season. This comparison relied on the establishment of corridors and quadrats at sites in the three national parks where wildflower tourism activities were evident. Three research sites across the study parks were utilised: in LNP—Lesueur Day use area (LD3) and Information Bay (LD4); and in SRNP—the Pay Station at Bluff Knoll (SD2) (Table 1; Fig. 2). The FRNP sites were not used (FD3, FD4) because they were burnt by wildfire.

Corridors were used for the LNP sites, with quadrats used in SRNP. For LNP, each site (n = 2) comprised three tourist use corridors and one control corridor (Kent and Coker 1992). The control corridor was selected to represent unused sites. The location and layout of the tourist use corridors was determined after observing wildflower tourists in the natural environment. Observations indicated they tended to radiate out from a central access point. Accordingly, the use corridors were arranged to radiate out from a central point to account for the typical wildflower visitors' movements. Locations of visitor use corridors were in areas of tourism interest and points of focus (i.e. exposed rocks, views of valleys, location of significant flowering plants) and were located off formal trails.

The corridors were 1 m wide (to enable use of a 1 m wide point intercept frame) and 7 m long (to account for visitors moving off a trail). Vegetation parameters were measured at eight cross-sectional points: 0, 1, 2, 3, 4, 5, 6 and 7 m, respectively. At each cross-sectional point 20 measurements from the point intercept frame were obtained, giving a total number of measurements for each transect corridor of 160. The corridors were measured out and reference pegs installed on both sides at intervals of one metre and GPS referenced. The vegetation parameters of vegetation height (cm) and vegetation cover (%) (comprising living and non-living plant matter) were measured at the beginning and the end of the wildflower season to ascertain if there was a change as a result of visitors trampling the vegetation during the wildflower tourist season.

At SRNP transect corridors were not used because park management agency staff were concerned that the point intercept frame could damage the threatened Dwarf Spider Orchid (*Caladenia bryceana* subsp. *bryceana*). As such, vegetation parameters were measured using a 1 m square quadrat. The square quadrat had a plastic frame and cross-wires to facilitate measuring vegetation parameters. The square was based on the conventional 1 m square with 10 cm × 10 cm subdivisions (Kent and Coker 1992). Four quadrats were placed along informal trails that were forming as a result of visitors leaving formal trails. A control quadrat was positioned further away with no formal access to its location.

Vegetation height and cover data recorded in the field were entered into Microsoft Excel 2010. The average vegetation height (cm) and living vegetation cover (%) was determined for each transect corridor/quadrat at the beginning of wildflower season (initial measurements) and the end of wildflower season (final measurements). The averages of the differences were determined and the standard error calculated.

Trampling experiment (study three)

Four research sites across the parks were utilised: in LNP—Near Lesueur Day Use Area (LE1) and Near Information Bay (LE2); in SRNP—South of Papercollar Bridge (SE1); and in FRNP—Near East Mt Barren Carpark 1 (FE1) (Table 1; Fig. 2). The other research site at FRNP was not used (FE2) because it was burnt by wildfire (Table 1; Fig. 2). The trampling experiments were undertaken some distance from the descriptive study sites to ensure there was no interference from visitors but ensuring the vegetation type and typography was a similar as possible. The widely-applied trampling experimental approach was used (Cole and Bayfield 1993; Malmivaara-Lamsa et al. 2008; Hill and Pickering 2009; Pickering and Growcock 2009; Hamberg et al. 2010; Pickering et al. 2011). This method has been designed to determine the relationship between amount of use and the impact on vegetation. The objectives of this experiment were to determine the effects "of trampling" on vegetation height and cover, as estimates of resistance and recovery of height and cover over a 12 month period, as a measure of resilience (Cole and Bayfield 1993).

The trampling experiment comprised 5 treatment lanes at each of the study sites, with each lane 1 m × 7 m with a cross sectional measurement undertaken every 0.5 m. Within each lane there were three replicates (displayed in Supplementary Information A). The standard dimension of the width of our treatment lanes differs from that of Cole and Bayfield (1993), in that the width of the treatment lane was increased from 0.5 to 1.0 m. This was to account for the nature of the vegetation communities (shrub-dominated vegetation) and to enable effective use of the point intercept frame, a reliable method that can be used to measure vegetation height and cover both on level and uneven ground (Kent and Coker 1992).

The treatment lanes at each site were positioned (with a 1 m buffer between them) according to areas of homogeneous vegetation structure less than 1 m in height, located on flat ground with no formal visitor activity (Cole and Bayfield 1993).

Treatments of 0 (control lane), 30, 100, 200 and 500 passes were selected. Previous Australian trampling studies have employed a range of trampling intensities including 0, 25, 30, 75, 100, 200, 300, 500 and 700 passes (Liddle and Thyer 1986; Whinam and Chilcott 1999, 2003; Phillips 2000; Growcock 2006). The shrub-dominated communities at the three national parks were expected to have a low to moderate resistance to trampling due to the communities being dominated by sclerophyllous shrubs so a maximum of 500 passes was determined as adequate for the study. The procedure for the application of the treatments to each lane was in accordance with Cole and Bayfield (1993) including random application of treatments.

Vegetation height and vegetation cover data were collected as part of the trampling experiment as these two parameters are scientifically credible, monitored with relative ease, cost-effective and can be easily re-measured (Cole and Bayfield 1993; Pickering and Growcock 2009; Hamberg et al. 2010; Pickering et al. 2011). Previous studies have shown that changes in physiognomic parameters (vegetation cover and vegetation growth/height) occur more quickly than changes in floristic parameters (vegetation composition) (Cole and Bayfield 1993; Whinam and Chilcott 1999).

Vegetation height and cover were measured before trampling, immediately after trampling, 2, 6 weeks and 1 year after trampling in line with the approach of Cole and Bayfield (1993). These data were collected using the point intercept frame. The frame was positioned at each cross section (Supplementary Information A) and 20 measurements (number of frame pins) for vegetation height and cover were recorded. The number of recorded measurements taken in each replication was 100 measurements. The number of recorded measurements taken for the whole treatment lane (all three replications) was 300 measurements. The data collected in each of the three replications were used in the analysis of vegetation cover. The data collected for the whole treatment lane was used in the analysis of the vegetation height.

Vegetation height and percentage cover values recorded in the field (absolute values) were utilised in analyses. Relative values are defined as the 'proportion of initial conditions (height or cover) with a correction factor applied to account for spontaneous changes on the control plots' (Cole and Bayfield 1993, p. 211). Absolute values rather than relative values are being used increasingly in the analysis of trampling data (Pickering and Growcock 2009; Hamberg et al. 2010; Pickering et al. 2011). To address distributional assumptions underlying the statistical analyses utilised, vegetation heights were transformed using a square root transformation, and percentage vegetation cover values were transformed using the arcsine square root transformation.

To ascertain the effect of trampling on vegetation height, cover and recovery across the four sites, we used linear mixed effects models (LMEM). Vegetation height data were analysed using two different LMEM and fit using R (R Development Core Team 2013) and the "nlme" package for R (Pinheiro et al. 2013). The first model compared the pre- and post-trampling vegetation height data. Fixed effects included an indicator for whether the measurement was taken before or after trampling, number of passes, site, and all possible interactions among the three variables. Random effects were included for lanes for given sites. To account for spatial correlation in vegetation heights across the various point intercept frame locations for a given site and lane, an exponential isotropic variogram model was applied (Cressie 1993). A second model examined the post-trampling vegetation height data and vegetation recovery over time, also using a LMEM. Fixed effects included the initial vegetation height, number of passes, site, weeks since initial trampling, and an interaction between number of passes and weeks since initial trampling. Random effects and an exponential isotropic variogram were specified in the same manner as for the first model.

Post-trampling vegetation cover (as represented through percentage of living matter versus non-living plant matter) was analysed using a LMEM that included fixed effects for the number of passes, site, weeks since initial trampling, and an interaction between number of passes and number of weeks since initial trampling. Random effects were included for lanes within a site, and we assumed that vegetation cover percentages for individual lanes were independent of those for other lanes. Given the small variation in life form categories and low prevalence of living matter across all lanes post-trampling, instructive analyses incorporating individual life forms were not possible, so the focus was restricted to analyses comparing living matter versus non-living matter.

The resistance index for each site was calculated. The index is the number of passes required to cause a 50 % reduction in the original vegetation cover (Liddle 1997). Rainfall data for the three parks for the study period (12 months) were obtained from the Bureau of Meteorology.

Results

Observations of the visitors to the national parks (study one)

After 76 h of participant observation across the three national parks, 213 visitors (LNP n = 33, FRNP n = 51 and SRNP n = 129) were observed. Of the 213 visitors, 41 (LNP n = 11, FRNP n = 7 and SRNP n = 23) were observed leaving the trails. A key observation was that visitors who left established tracks followed a path of least resistance by heading towards bare ground and manoeuvring around larger shrubs and trees. During organised wildflower tours the researcher observed and recorded tourist behaviour in regard to accessing wildflowers in conjunction with information provided by the tour guides. Where the tour guides were strict regarding staying on the trail (two of the tours), there was little movement off trails and associated trampling. Where there was very little emphasis on staying on trails or the guides themselves moved off the trails (the other two tours) trampling occurred.

Descriptive studies (study two)

Effects of visitor trampling on vegetation height

In the descriptive studies the mean vegetation heights at all three sites declined in the corridors used by tourists, while vegetation height in the un-used (control) corridors increased. The vegetation heights for the controls at LD3, LD4 and SD2 increased over the sampling period (Supplementary Information B).

Effects of visitor trampling on vegetation cover

In the descriptive studies mean percentage cover of living material at all three sites declined in the corridors used by tourists, with mean percentage cover in the un-used (control) corridors either remaining unchanged or declining across the sampling period There was low percentage cover of living material, non-living material dominated the used sites and provided 52.08 % of the percentage initial cover at LD3, 48.33 % at LD4 and 80.56 % at SD2. The mean percentage vegetation cover at the control sites remained unchanged at LD3 and LD4 and declined by 1.5 % at SD2 (data indicated in Supplementary Information C).

Trampling experiments (study three)

Effects of trampling on vegetation height comparing pre and post (immediately after) measurements

The pre- and post-trampling vegetation height data for all sites were compared using a LMEM to determine the effects of trampling on vegetation height. Conditional F tests were used to determine the significance of individual terms in the model (Supplementary Information D), showing the pre- versus post-trampling variable ("pre- versus post-trampling") to be highly statistically significant (p value <0.001) and the trampling variable ("Passes") to be statistically significant (p value 0.0020). Examination of variable coefficients for the model demonstrated a significant reduction in vegetation height post-trampling and showed that vegetation height decreases with increased trampling (Supplementary Information E: refer specifically to coefficients for "pre- vs post-trampling", "Passes" and all interaction effects).

The result suggesting that vegetation height decreases with increased trampling may not be obvious, given that the coefficient for the "Passes" variable is statistically significant and positive (Supplementary Information E), suggesting increased vegetation height with increased trampling. Note, however, that the effect of trampling must account for the interaction effects including "Passes," and the negative coefficient for the interaction effect between number of passes and whether the measurement was taken pre- or post-trampling ("pre-/post-trampling × Passes") more than offsets any positive coefficients, resulting in a net effect that is negative for each site.

Figure 3 also illustrates for all the intensities of trampling (30, 100, 200 and 300/500) the dramatic decline in vegetation height immediately post trampling.

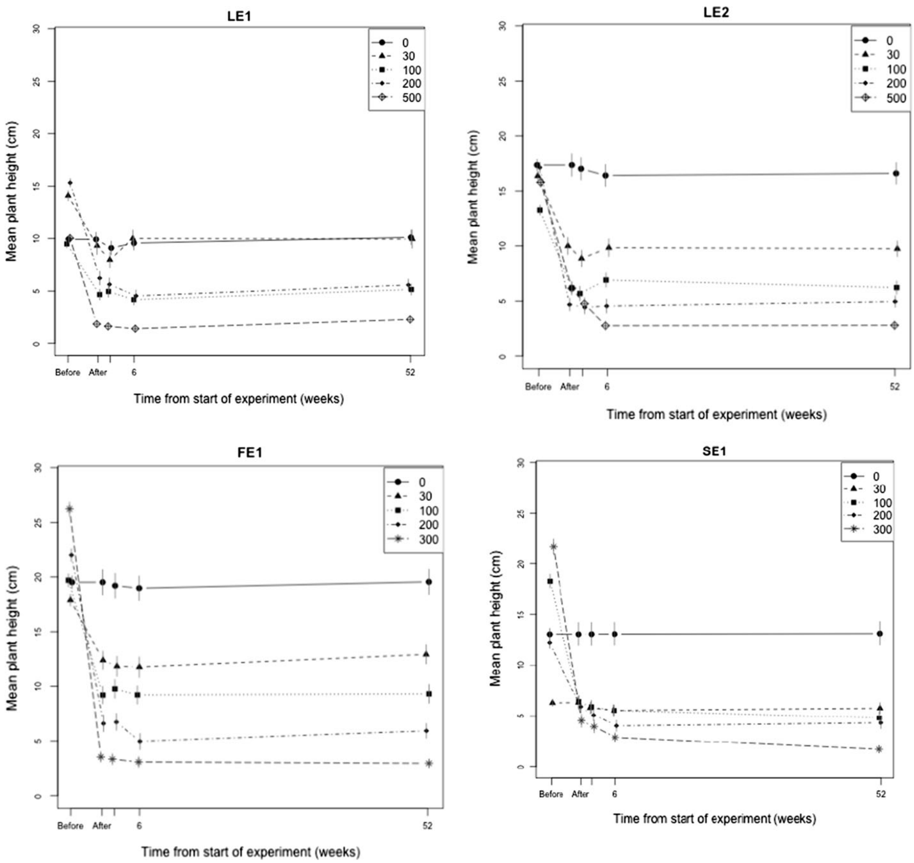

Fig. 3 Mean vegetation heights (and corresponding standard errors, represented as *vertical bars*) for the four sites during trampling experiment study before trampling, immediately after trampling, and 2, 6 and 52 weeks after trampling

Effects of trampling on the recovery of vegetation height post trampling over a 12-month period

The second LMEM, which focuses on vegetation heights post-trampling and vegetation recovery over time, confirmed the result of the first model in terms of trampling leading to a significant reduction in vegetation height. A conditional *F* test of number of passes showed the number of passes to be highly statistically significant (Supplementary Information F, p value <0.0001). The coefficient for the "Passes" variable was highly statistically significant and negative, and the coefficient for the interaction effect ("Passes × Weeks") including number of passes was also negative (Supplementary Information G), consistent with vegetation height decreasing with increased trampling. At the same time, however, vegetation height post-trampling was not significantly related to weeks since initial trampling (shown in Supplementary Information H, p value 0.9582), a result consistent with that shown in Supplementary Information H, where lines corresponding to post-trampling time periods all lie in very close proximity to each other. Consequently, the results show no significant recovery.

Effects of trampling on vegetation cover post trampling over a 12 month period

In all four sites (LE1, LE2, FE1 and SE1), all intensities of trampling (30, 100, 200 and 300/500 passes) caused the percentage cover of living matter to decrease, as illustrated in Fig. 4 and Supplementary Information I. A conditional *F* test shows a significant relationship between the percentage of living matter and the number of passes (Supplementary Information J, "Passes" p value <0.0001) with increased trampling associated with a reduction in the percentage of living matter (Supplementary Information K, statistically significant negative coefficients for "Passes," non-significant interaction effect for "Passes × Weeks" with a net negative effect). This is in line with what is observed as displayed in Supplementary Information I. After 30 passes the percentage of living vegetation cover decreased from 53.33 to 37.33 % at LE1, 68.0 to 27.67 % at LE2 and from 62.0 to 47.67 % at FE1 post trampling. A much smaller decrease was recorded for SE1 (40.34–39.0 %) at 30 passes but after 100 passes the percentage of living vegetation cover decreased from 54.0 to 34.99 %.

Similarly to changes in the vegetation height in response to trampling, the relationship between the percentage cover of living matter and number of weeks since trampling is non-significant (Supplementary Information J, "Weeks" p value 0.0854).

The living matter in the treatment lanes comprised shrubs, grasses, herbaceous species, sedges, ferns, mosses and liverworts. Characterization of the major living life forms (e.g. Tables 1, 2) at each trampling experiment site showed that shrubs dominated all four vegetation communities. Prior to trampling, the proportion of the shrubs (averaged across all the lanes) and grasses (averaged across all the lanes) accounted for:

- LE1: shrubs (52.87 %) and grasses (5.60 %);
- LE2: shrubs (59.40 %) and grasses (5.73 %);
- FE1: shrubs (49.60 %) and grasses (16.67 %); and
- SE1 shrubs (35.20 %) and grasses (18.27 %).

While the proportion of non-living material (averaged across all the lanes) accounted for:

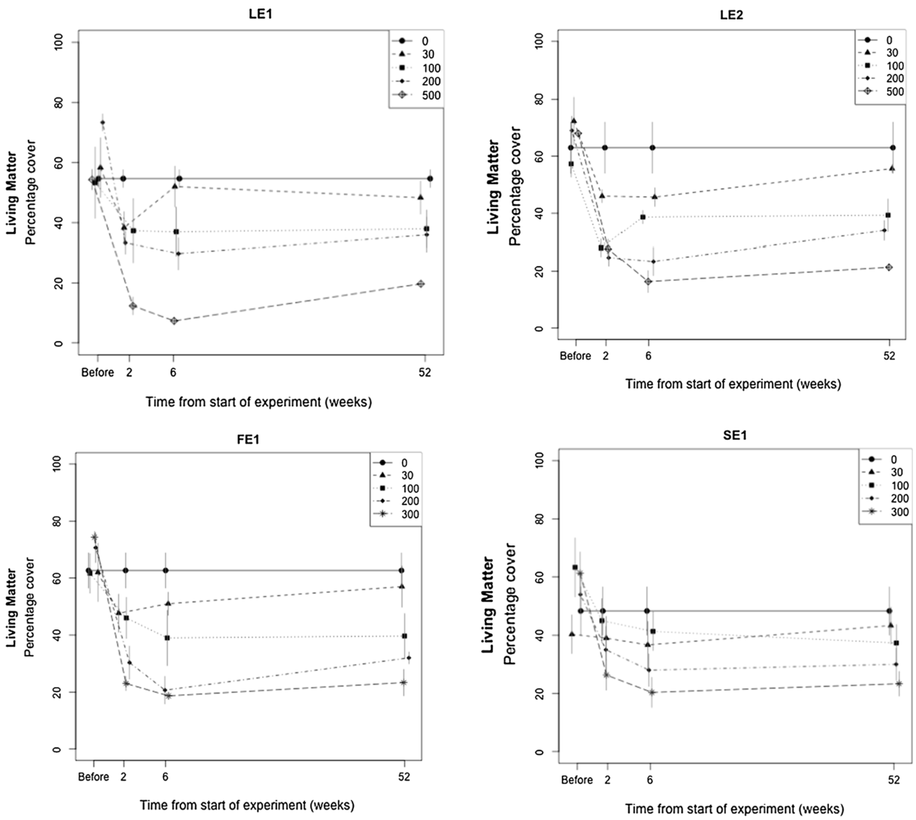

Fig. 4 Percentage cover of living matter (and corresponding standard errors, represented as *vertical bars*) for the four sites during trampling experiment study before trampling, immediately after trampling, and 2, 6 and 52 weeks after trampling

- LE1: dead material and bare ground (41.20 %);
- LE2: dead material and bare ground (34.07 %);
- FE1: dead material and bare ground (33.73 %); and
- SE1: dead material and bare ground (46.53 %).

Calculation of resistance index

A resistance index is the number of passes required to cause a 50 % reduction in the original value of vegetation cover (Liddle 1997). The index was determined by analysing the vegetation cover data for each National Park (Supplementary Information L).

Rainfall

The rainfall for the 12-month study period was below the long-term average for two of the national parks—LNP was 213.5 mm below average and SRNP was 73.8 mm below average. For FRNP rainfall was 22.1 mm above average (Supplementary Information M).

Discussion

Overview

The observations of visitors, descriptive, and experimental trampling studies reported in this paper provide much needed data on the effects of trampling on shrub-dominated communities that form a critical part of the southwest Australia biodiversity hotspot. National parks provide an obvious point for research focus given they are a nexus between high biological values and increasing attention from the tourism industry. No previous studies have determined the effects of trampling by tourists in this international biodiversity hotspot and its national parks. This biome is considered highly vulnerable to disturbance because of high plant specialisation to nutrient deficient soils, a high degree of endemism and restricted population sizes occurring in a Mediterranean climate (Hopper and Gioia 2004; Hopper 2009; Laliberte et al. 2014; Barrett and Yates 2014).

Resistance of vegetation height to trampling

This study has shown that at low levels of trampling there was a considerable decrease in vegetation height in the shrub-dominated communities of LNP, FRNP and SRNP. All trampling intensities (30, 100, 200 and 300/500 passes) (Fig. 3) caused a significant decrease in vegetation height immediately following trampling for all three communities. The results demonstrate a decline in vegetation height greater for higher trampling intensities and that shrub-dominated communities have a low resistance to trampling by tourists.

Such low resistance can be explained by the following characteristics of the dominant genera (e.g., *Hakea*, *Acacia*, *Banksia*, *Melaleuca*, *Leucopogon* and *Verticordia*) (Table 2) occurring in the national parks:

1. Shrub life form (morphological trait) leading to sensitivity to trampling (Bayfield 1979; Griffin and Hopkins 1981; Cole and Spildie 1998; Specht and Specht 1999; Pickering and Hill 2007; Pickering and Growcock 2009);
2. Erect growth form (morphological trait) leading to low resistance (Griffin and Hopkins 1981; Sun and Liddle 1991; Liddle 1997; Cole and Spildie 1998; Specht and Specht 1999; Pickering and Hill 2007; Pickering and Growcock 2009); and
3. Woody stems and presence of sclerenchyma (anatomical trait) leading to low resistance (Griffin and Hopkins 1981; Sun and Liddle 1993b; Yorks et al. 1997; Specht and Specht 1999; Pickering and Hill 2007; Pickering and Growcock 2009).

Another Australian study conducted in a shrub-dominated community in the feldmark vegetation in Kosciuszko National Park. McDougall and Wright (2004) found that shrubs were more susceptible to trampling (they had low resistance) than other life forms and their findings support the results of this study.

Worldwide there have been few studies conducted on the impacts of trampling on shrub-dominated communities. For example, the Lolo National Park (USA) study found the shrub-dominated community was more resistant than the forb-dominated community, which is in contrast to our findings (Cole and Spildie 1998). An explanation for this difference is that vegetation in the USA has evolved in the presence of hard hoofed animals resulting in vegetation communities being more resistant to trampling damage than the shrub-dominated plant communities in Australia which have evolved in the absence of hoofed native herbivores (Newsome et al. 2002; Pickering and Hill 2007). Such differences between environments demonstrate the importance of conducting experimental trampling studies in shrub-dominated communities worldwide.

The descriptive studies in LNP and SRNP also demonstrate a reduction in vegetation height in the used corridors/quadrants. Even low levels of trampling over a wildflower season can cause significant damage to vegetation because of potential damage to flowering parts and other reproductive structures (Liddle 1997; Barros et al. 2013). The impact of a low number of visitors to LNP was noticeable when comparing the used corridors and quadrats to the controls. This finding is also supported by other studies that have shown that low levels of off-trail traffic can wear down vegetation (Wimpey and Marion 2011).

Resistance index (vegetation cover)

It is evident from this study (see Supplementary Information H and K) that even at low levels of trampling there was a substantial change in vegetation cover, which is in accordance with studies undertaken elsewhere (Kuss and Hall 1991; Hamberg et al. 2010; Bernhardt-Romermann et al. 2011). The resistance index at the Stirling Range National Park study sites (300 passes) was the most robust out of the three national parks. One reason could be that the vegetation community at SRNP had the highest proportion of grasses and non-living material relative to the other two national parks. Previous studies have indicated that the grass life form is more resistant and resilient to trampling than shrub life forms (Sun and Liddle 1993c; Liddle 1997; Yorks et al. 1997; Whinam and Chilcott 1999; Hill and Pickering 2009). Grasses tend to have basally-fixed meristems, flexible cells, papery sheaths, increased tiller production and reduced height and leaf size which enable them to resist and recover more effectively from trampling (Sun and Liddle 1993c; Liddle 1997; Hill and Pickering 2009). This could account for the larger resistance index at SRNP when compared to LNP (30 and 100 passes) and FRNP (100 passes).

Resistance indices for different vegetation communities, as compiled by Liddle (1997), show a wide range of responses from 12 passes to 1412 passes required to reduce the vegetation cover by 50 %. The resistance indices for Western Australian shrub-dominated communities were low (30–300 passes) when considering this possible range. Other vegetation communities having low resistance indices to human trampling include Eucalyptus woodland in Brisbane, Australia (12 passes), the snow-bank community in the Snowy Mountains, Australia (44 passes) and spruce woodland ground flora in Finland (48 passes) (Liddle 1997; Newsome et al. 2013). It is important to note that in the global context there is likely to be variation in the resistance index for shrub-dominated communities and this is evident when examining the resistance indices from Australian work and this study (Hill and Pickering 2009).

Resilience (recovery) of vegetation (cover and height) to trampling impacts

Trampling experimental work conducted over the period of this study indicates that resilience (recovery) of the vegetation to be poor. As time increased recovery indicators (plant height and proportion of living material) either decreased or remained flat across all three national parks (Fig. 3; Supplementary Information H). The time variable was determined to have a non-significant influence on vegetation recovery. In essence there was virtually no growth, such as an increase in vegetation height in the control and treatment lanes post trampling. The minimal resilience (recovery) of the vegetation height and cover over the sampling period, which included the growing season, can be attributed to a combination of factors including plant characteristics, climatic conditions during the study, and soil types evident in the national parks. Soils in much of the south west of Western Australia are extremely infertile (e.g. Pate and Beard 1984; Specht and Specht 1999; Lambers et al. 2010; Laliberte et al. 2014). Although the flora has evolved a wide range of nutrient acquisition strategies to enhance nutrient uptake (e.g. Pate and Beard 1984) and respond to fire related disturbances (e.g. Deifs et al. 1987) recovery of biomass is relatively slow where repeated trampling disturbance degrades plant structure and disrupts subtle surface soil and plant root associations (Phillips and Newsome 2002; Hopper 2009).

The effects of trampling thus exacerbate natural environmental stress especially when plant reproductive structures are lost/damaged and where soil disturbance takes place. In this study the slow or absence of growth of dominant plant genera (*Hakea*, *Acacia*, *Banksia*, *Melaleuca*, *Leucopogon* and *Verticordia*) (Table 2) evident over a 12-month period thus relates to the propensity for plant growth to be naturally limited by the availability of water and nutrients (e.g. Yorks et al. 1997; Specht and Specht 1999; Hopper and Gioia 2004).

Malmivaara-Lamsa et al. (2008) found that in Finland the tolerance (combining resistance and resilience) of vegetation increased with fertility of the soil. Lambers et al. (2010) and Laliberte et al. (2014) point out that in the nutrient deficient landscapes of south Western Australia the low availability of plant nutrients constrains plant productivity. Such soil conditions mean that it could take a long time for many plant species to recover from trampling disturbance. Hopper (2009) points out that recovery from disturbance is also closely linked to soil surface conditions as the top 5–10 cm of soil is an important repository of micro-organisms and seed which are vital for recovery following disturbance. Damage to this thin soil layer could further limit the capacity of the biodiverse heathlands of Western Australia to recover from trampling by visitors.

Climatic conditions during the sampling period additionally help to explain the low resilience (recovery) of vegetation in both the treatment and control lanes. For example, Bernhardt-Romermann et al. (2011) reported that resilience is largely dependent on active plant growth which is directly connected to climate. The three national parks are characterised by a Mediterranean climate with wet winters and dry summers (Beard 1990; Hopper and Gioia 2004). Rainfall data (Supplementary Information M) shows that LNP (213.5 mm below the average) and SRNP (73.8 mm below the average) had lower than average rainfall. The lower than average rainfall at these sites is likely to have affected the growth and ability of vegetation to recover. At FRNP there was a significant rainfall event during the summer period in January (115 mm) which when compared to the average January rainfall (21.6 mm) was well above the average. However, this rainfall fell outside of the growing season and would have had a minimal positive effect on plant community growth and ability to recover post-trampling.

Recovery following damage of vegetation caused by recreation and tourism activities is likely to be slowed down under sub-optimal soil moisture conditions brought about by drought and reduced seasonal rainfall. The evidence for climate change and predictions for a continual decline in winter rainfall for southwest Western Australia (Stott et al. 2010; Dai 2013; Watson et al. 2013) is an additional factor that exacerbates the sensitivity of this vegetation to damage from tourists and other visitors.

Management implications for recreation and tourism

The findings reported in this paper are of great importance given that the parks are an interface between biodiversity and tourism and that these environments are highly vulnerable and under threat (Myers et al. 2000; Hopper and Gioia 2004). Observations of tourists and the evidence of tramping damage indicate that both independent travellers and tour operator led groups need additional management attention (Table 3).

Access into protected areas is facilitated via trail networks. There are a wide range of trail designs that can be applied depending upon environmental conditions and the level of visitation (see Newsome et al. 2013). Where trail networks are unsustainable the risk of visitors leaving trails due to eroded sections and waterlogging increases (Marion and Leung 2004; Newsome et al. 2013). Tourists leaving formed trails and crossing barriers that are designed to protect vegetation from trampling can create constant, year-to-year, low level trampling likely to result in localised site degradation and the unappealing look of damaged vegetation may displace visitors into more pristine areas. The significance of such behaviour will depend on the levels of visitation, the extent to which new areas are visited, presence of other recreational activities that may damage vegetation and the efficacy of existing trail management practices (Newsome et al. 2013). Practices vital to keeping visitors on formed paths include a comprehensive programme of trail management and monitoring and it is important that resources, expertise and staff are available to achieve trail sustainability (Mende and Newsome 2006; Marion and Reid 2007; Marion and Leung 2011; Marion et al. 2011). Monitoring for indicators of trail degradation, which can lead to compromised trail

Table 3 Recommendations for additional management attention in regard to increasing wildflower tourism in biodiversity hotspots

Management strategy	Additional information
Educational programs for tour operators that convey messages about the effects of trampling and the low resilience and resistance of these highly valued plant communities	Boon et al. (2008), Cole et al. (1997), Littlefair (2004), Parks and Wildlife (2015)
The installation of interpretive panels at tourism activity nodes that highlight the sensitivity of the vegetation and provide information about the consequences of trampling on vegetation and species of tourism interest	Boon et al. (2008), Cole et al. (1997), Marion and Reid (2007), Newsome et al. (2013)
Effective trail signage to minimize visitor movement off formal trails and the potential creation of informal trails	Marion and Leung (2004), Newsome et al. (2013)
Provision of boardwalks that allow for discovery and seclusion opportunities while minimising the movement off formal trails by visitors	Randall and Newsome (2008), Newsome et al. (2013)
Creation and design of new trails and/or upgrading existing trails	Mende and Newsome (2006), Marion and Leung (2004, 2011), Marion and Reid (2007), Marion et al. (2011), Randall and Newsome (2008)
Ongoing monitoring with a view to closing some sites so that there is scope for the recovery of sites damaged by trampling	Leung et al. (2011), Monz et al. (2010a, b), Newsome et al. (2013), Walden-Schreiner et al. (2012)
Where appropriate placing physical barriers to minimise the movement off formal trails	Barros et al. (2013), Kim and Daigle (2012), Roovers et al. (2004)
Further research in shrub-dominated communities in other biodiversity hotspots to build knowledge regarding the resilience and resistance of these communities to trampling and other impacts associated with tourism	Ballantyne et al. (2014), Newsome et al. (2013)

trafficability, and particularly informal trail development are important considerations especially as informal trails are a measure of off-trail impacts and de-facto trampling of vegetation. Hardened trail surfaces have proven to be effective in containing trail impacts in sensitive environments but are expensive to install and maintain (Hawes and Dixon 2014). However, when planned, installed and maintained trails can be effective in directing and managing visitor access (Marion and Leung 2004; Randall and Newsome 2008)

Educational programs are also widely employed in protected areas to encourage appropriate tourist behaviours (Boon et al. 2008; CALM 1999; Cole et al. 1997; Littlefair 2004; Marion and Reid 2007; Newsome et al. 2013). In Western Australia this is particularly important because of the risk of both on and off-trail activity spreading plant pathogens such as *Phytophthora cinnamomi* (dieback disease). *Phytophthora cinnamomi*, for example, is already present along walk trails in SRNP and along access roads in FRNP so the risk of further spread as a result of tourism access is real (Newsome 2003; Buckley et al. 2004). Up to 2800 species of plant in SWA are susceptible to dieback disease caused by *Phytophthora cinnamomi* and further tourism and recreation mediated spread of the pathogen constitutes a major risk for this biodiverse region (Shearer et al. 2004). Educational programmes combined with dieback hygiene, involving the provision of hiking boot-cleaning stations and sometimes trail closures, have been, and are currently, applied in at-risk protected areas in Western Australia (Newsome 2003; Parks and Wildlife 2015).

Although educational strategies can be problematic in regard to the attention paid to low impact messages, Boon et al. (2008) reported greater effectiveness when interpretation was directed to an individual's sense of responsibility. Appropriate behaviour modelling by tour operators, highlighted by Littlefair (2004) and Newsome et al. (2013), is an especially important consideration given the findings reported in this paper. If monitoring for informal trail development and associated trampling of vegetation data reveal that education is not working, as indicated in some studies (for example, Park et al. 2008; Guo et al. 2015), park management may have to employ more direct management actions such as policing by rangers during the peak wildflower tourism season.

Conclusion

The work presented in this paper provides data on the impacts of trampling within an international biodiversity hotspot. Such damage not only constitutes a risk to biodiversity but also to the wildflower tourism resource itself. Using established methodologies this study demonstrates that low levels of trampling cause significant damage to the shrub-dominated communities characterising the vegetation of LNP, FRNP and SRNP and that these plant communities have a low resistance to human trampling disturbance. Furthermore, measurements of trampling impacts at selected intervals over a 12-month period suggest that the vegetation communities also have low resilience to human trampling. Plant characteristics that help to explain the sensitivity of vegetation to trampling are an erect growth form, woody stems, shrub life forms and low productivity. Season of use is an important consideration as the production of flowers and other reproductive structures coincides with peak visitor activity and likely impact. An additional stress factor hindering the recovery of vegetation from trampling damage is seasonal drought especially if this occurs during the growing season.

Tourism is one of a group of threatening processes (e.g. see Pickering and Hill 2007; Pickering 2010) that include the presence of feral animals, invasive weeds, spread of fungal pathogens, altered fire regimes and climate change (Burgman et al. 2007). Perhaps considered as the least significant of these threatening process this work has shown that recreational damage via trampling has the capacity to degrade a highly valued tourism resource. The results of this research show the sensitivity of these vegetation communities to trampling and the trampling impact of visitors needs to be effectively managed to protect these communities. Given the increasing visitation to protected areas in Western Australia (TWA and DEC 2010) the promotion of the wildflower tourism industry overseas and a societal push for greater participation in outdoor activities it is important that all of the potential risks associated with trampling biodiverse vegetation are actively conveyed to all. Furthermore, the findings and recommendations derived from this work can be set within an international context in that the biodiverse vegetation communities occurring in the Mediterranean ecosystems of South Africa and South America are also facing increased recreational pressures. Accordingly this work adds to the trampling impact database and provides a useful comparison and platform for further work on the impacts of trampling on biodiverse shrub land communities.

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