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Spatial patterns of recreation impact on experimental campsites

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Abstract

Management of camping impacts in protected areas worldwide is limited by inadequate understanding of spatial patterns of impact and attention to spatial management strategies. Spatial patterns of campsite impact were studied in two subalpine plant communities in the Wind River Mountains, Wyoming, USA (a forest and a meadow). Response to chronic disturbance and recovery from acute disturbance were both assessed. Previously undisturbed sites were camped on at intensities of one and four nights/year, for either one or three consecutive years. Recovery was followed for three years on sites camped on for one year. Percent bare ground, assessed in 49 contiguous 1 m^2 quadrats, increased with increasing use frequency, particularly on the forest sites. Magnitude of impact varied spatially within campsites, with impact decreasing as distance from the center of the campsite increased. On the more fragile forest sites, this radial impact pattern developed rapidly and remained after three years of recovery. Concentration of camping activities around a centrally located small cooking stove was the apparent cause of this pattern. Maximum variation in magnitude of impact occurred at intermediate levels of campsite use and disturbance. The magnitude, variability and spatial pattern of impact varied with the spatial scale of analysis. Generally, results of these controlled experiments are consistent with earlier studies of campsites and validate the management implications derived from those studies. Even where campers use low-impact techniques, low levels of camping use can cause substantial impact and it is important to concentrate use. On resistant sites, however, it is possible that low levels of use can be sustained with minimal resultant impact.
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1. Situation

Managers of protected areas worldwide are challenged to respond to numerous threats to the integrity of the parks, wilderness areas and nature reserves they manage. Demand for ecotourism and recreational use of protected areas are among the foremost threats in many places (Newsome et al., 2002). The nature of recreational use and its resultant impacts are highly variable. Particularly in more remote parks and wilderness areas, where a developed infrastructure is largely absent, the impacts associated with overnight camping are a critical concern (Manning et al., 1996). Consequently, a substantial amount of research has been conducted on the impacts of camping. Much is known about the nature of these impacts and the factors that influence the magnitude of impacts (Leung and Marion, 2000). Most of this work has focused on the intensity of change on individual campsites, with numerous studies providing descriptive data for such impact parameters as decreases in percent vegetation cover and increases in soil compaction. Relatively few studies have examined the spatial patterns of campsite impact or examined impacts at multiple scales. This is unfortunate because management strategies must consider both the intensity of disturbance and the spatial extent of those impacts, particularly in places where recreationists are allowed to camp wherever they want.

2. Problem analysis

Empirical studies of temporal patterns of campsite impact have always concluded that impact occurs rapidly (Merriam and Smith, 1974). Although rates of impact can be estimated from studies that report conditions prior to and after camping, repeat measurements have only

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been taken after impacts are already pronounced (Marion and Cole, 1996). Consequently, we know little about the incipient stages of campsite development. Trend studies also illustrate the importance of considering spatial patterns when describing change over time. Typically trend studies have found increases in the extent of impact (the area disturbed by camping) to be more pronounced than increases in the intensity of impact on individual sites (Merriam and Smith, 1974; Marion and Cole, 1996). In the Eagle Cap Wilderness, Oregon, for example, the size of individual campsites increased substantially over a period of 11 years, but the mean vegetation cover on campsites was relatively stable (Cole and Hall, 1992). In addition to an increase in the size of individual campsites, the number of campsites also increased over this period (Cole, 1993).

Several early papers on campsite impact management strategies emphasized the importance of understanding and influencing spatial patterns of use and impact. McEwen and Tocher (1976) provided an early discussion of design principles capable of minimizing the extent of impact at the scale of the individual campsite, while Cole (1981) described management strategies for minimizing the aggregate extent of campsite impact at the scale of a park or wilderness area. More recently, Leung and Marion (1999a) have described spatial strategies for managing impact and empirical work has documented reductions in aggregate campsite impact resulting from management actions that concentrated use both within and among campsites (Marion, 1995; Spildie et al., 2000).

One of the most common observations about spatial pattern on campsites is that there is a gradient of decreasing vegetation impact from the largely barren central portion of the campsite to the edge of the campsite (Frissell, 1978). Based on the commonsense assumption that this pattern is the result of activity concentration close to the center of the site, Cole (1992) developed simple analytical models of campsites. Unfortunately, these models and most interpretations of the results of campsite impact and trend studies continue to rely on casual observation and commonsense assumptions about camping behavior and the processes by which impacts develop in space and time.

The lack of empirical studies that demonstrate how spatial patterns develop on campsites, how rapidly they develop, and how long they persist limits our ability to interpret the results of campsite impact studies. This paper attempts to partially address this limitation by describing the spatial and temporal patterns of impact that result from experimental applications of camping on previously unused sites. Since the 1960s (Wagar, 1964), experimental trampling has been employed to assess the impacts of trampling under controlled circumstances. Controlled experimental camping studies, however, are rare (Cole, 1995; Gniesser, 2000).

3. Objectives

Specific objectives of the work reported in this paper were to describe the magnitude and dynamics of spatial variation in the magnitude of groundcover disturbance (as indicated by changes in bare ground) on campsites in two different plant communities. As suggested by Bender et al. (1984), we sought the insight to be gained by assessing response to both acute and chronic camping disturbance. We documented the response of groundcover to three successive years of camping (chronic disturbance) at two different use intensities (one and four nights/year of camping), as well as three years of recovery following a single year of camping (acute disturbance). This work is one component of a larger study of the consequences of dispersed hiking and camping on high-elevation plant communities. Other papers report the results of trampling experiments (Cole and Monz, 2002) and the effects of use frequency on experimental campsites in two plant communities (Cole and Monz, 2004).

3.1. Methods

3.1.1. Study area

The camping experiments were conducted in ecosystem types characteristic of the subalpine zone of the Middle Rocky Mountains, USA. Two study sites were located in the Popo Agie Wilderness, Wind River Mountains, northwestern Wyoming. The two sites were located about 3 km apart, in headwater watersheds of the Middle Fork of the Popo Agie River. Experiments were conducted in two plant communities that (1) are commonly used for overnight camping; (2) had groundcovers that were physiognomically different from each other (and therefore likely to vary in response to camping); and (3) had substantial groundcover. One plant community, located at an elevation of 3100 m (42° 41′ 00″ N latitude, 109° 00′ 30″ W longitude), was a subalpine coniferous forest with groundcover dominated by the low-growing shrub, *Vaccinium scoparium*. *Pinus contorta* and *Pinus albicaulis* were the most abundant mature tree species. We refer to this site as the forest with *V. scoparium* understory. The second plant community, located at an elevation of 3125 m (42° 40′ 15″ N latitude, 109° 02′ 30″ W longitude), was a riparian meadow surrounded by subalpine forest. This meadow contained a dense, diverse assemblage of graminoids (e.g. *Deschampsia cespitosa*, *Agrostis humilis*, *Phleum alpinum*, *Juncus drummondii*, and various species of *Carex*) and forbs (e.g. *Antennaria corymbosa*, *Caltha leptosepala*, and *Potentilla diversifolia*). We refer to this as the *D. cespitosa* meadow. Further information on the species composition of these plant communities and their response to experimental trampling can be found in Cole and Monz (2002). Both sites were located in glaciated topography on soils derived from granitic bedrock. The forested campsites were on flat to gently sloping benches perched above a string of valley-bottom meadows and ponds. The meadow sites were on flat to gently sloping terraces within 25 m of a meandering creek.

3.2. Field methods

In each of these two plant communities, we located 16 potential campsites spread over an area of approximately 5 ha. Each potential campsite was a square, 7 m on each side, with short stakes in each corner and at the center of the site. Eight of the sites were camped on for a single season, while the other eight were camped on for three years in a row. Within each of these groups of eight, four sites were camped on one night/year, while the others were camped on four nights/year. To the extent possible, the timing of use within a year, on sites camped on four nights/year, was equivalent on all sites. Camping occurred between late July and mid-August, when the standing crop of vegetation was close to its peak. Camping treatments were applied by backpackers enrolled in courses offered by the National Outdoor Leadership School (NOLS). NOLS courses, which typically last for about 28 days, teach students the skills associated with outdoor recreation and leadership.

In order to reduce the impact of NOLS courses, students typically travel and camp in several groups of four, coming together infrequently for group sessions. Camping treatments were applied by groups of four people camping together on one of the potential campsites. Typically, on any given treatment night, groups of four were directed to camp on four of the experimental campsites. They were instructed to drop their backpacks and set up their tent anywhere within the 49 m^2 campsite and to set up their cooking stove (small, gas-fueled, <1 kg) at the location of the center stake. Otherwise they were told to behave as they normally would, coming and going from the site as they pleased.

Individual campers vary in their potential to cause impact (with such factors as their experience, attitudes, weight and behavior) and individuals were not randomly assigned to groups. However, because groups were randomly assigned to campsites, there is no reason to expect a systematic bias between treatments. It is possible that camping behavior varies systematically between forest and meadow. If so, the differences in impact between the two vegetation types that we found in this study may reflect differences in camper behavior as well as in durability of the vegetation type. Of more potential concern, the artificiality of the behavioral constraints that we imposed could have reduced differences in behavior that would normally exist between forest and meadow campers.

NOLS courses emphasize Leave No Trace techniques for minimizing the impacts associated with recreation use (Hampton and Cole, 1995) and students must adhere to these techniques. For example, campfires were not built on any of the experimental campsites. Therefore, the magnitude of disturbance associated with these experimental treatments should be close to the minimum possible for the amount of use applied.

On each campsite, measurements were taken within a rope grid that divided the campsite into 49 one square meter quadrats. In each of these quadrats we estimated percent cover of bare ground. Bare ground was defined by the lack of vegetation canopy and can consist of rock, mineral soil or organic litter. Bare ground was recorded as 0 if absent and 0.2% if less than 0.5% cover. Otherwise it was recorded as the closest of the following values: 1, 5, 10, 15, 20, 30, 40, 50, 60, 70, 80, 90, or 100%. Initial measurements of bare ground were taken on each of the 16 campsites in each of the two plant communities within a week before the commencement of camping treatments. On the sites camped on for three successive years, pre-camping measurements were taken each year and post-treatment measurements were taken within a week after the last night of camping each year, and one year after the final camping treatment. On the sites camped on for one year, measurements were only taken once per year for the final three years of the experiment.

Changes in bare ground on these campsites result from both the effects of camping and other uncontrolled factors (such as yearly climatic variation). To factor out these uncontrolled sources of variation, we used data from four control sites in each of the two plant communities. Control sites were similar to campsites, but smaller, and intermixed with the campsites. On each control, four 30×50 cm quadrats were established 0.5–1.0 m from a center stake, on transects oriented in each of the cardinal directions from the center. Percent cover of bare ground on controls was estimated in a manner analogous to estimates on campsites, before and after each application of camping treatments. Sampling procedures for controls differed from those for campsites because their primary purpose was for comparison with changes on small quadrats located in the central portion of campsites and reported in Cole and Monz (2004). These differences in sampling procedures should not be a concern because the only purpose of the measures on controls is to adjust change measures on the campsites, with the adjustment term being identical for all quadrats in all campsites in each plant community.

3.3. Data analysis

For each of the 49 quadrats on each campsite, change in bare ground was calculated by subtracting pre-treatment estimates from post-treatment estimates and adjusting for changes on controls. Change in bare ground is

$$((Post_{campsite} - Pre_{campsite}) - (Post_{control} - Pre_{control})) \times 100\%,$$

where $\mathrm{Pre}_{\mathrm{campsite}}$ and $\mathrm{Pre}_{\mathrm{control}}$ are the initial percent cover of bare ground on campsites and controls, respectively, and $\mathrm{Post}_{\mathrm{campsite}}$ and $\mathrm{Post}_{\mathrm{control}}$ are the post-camping percent cover of bare ground on campsites and controls, respectively. Control estimates, which are identical for all quadrats in all campsites in each plant community, are the mean of four quadrats in each of four controls.

To quantify the magnitude of impact at the scale of the entire campsite, estimates for each of the 49 quadrats on each campsite were combined into single measures of mean change in bare ground. In this paper, however, we are more interested in an estimate of the spatial variation in impact on individual campsites. We quantified variability in two ways. Our primary indicator of variability was the standard deviation of the 49 estimates of change in bare ground taken on each campsite. This provides an absolute estimate of variability. We also calculated coefficients of variation (standard deviation divided by the mean, expressed as a percent).

To explore spatial regularities in the distribution of impact, we calculated mean change in bare ground in three concentric zones on each campsite: the nine innermost 1 m^2 quadrats, the 16 quadrats that surround this central zone, and the 24 quadrats that surround these (Fig. 1). Finally, we mapped the pattern of impact on each campsite by assigning an impact rating, between one and five, to each quadrat depending on whether bare ground increase was (5%, 5–10%, 10–20%, 20–50% or >50%).

We used repeated measures ANOVA (GLM Repeated Measures, SPSS, Ver 9.0) for all our inferential statistics. Our primary interest was in assessing the magnitude of differences in impact and recovery between the three concentric campsite zones. Campsite zone was a source of between subject variability, the significance of which was assessed with repeated type contrasts. First, we assessed whether the magnitude of response to camping varied with years of camping or recovery, nights of camping per year, plant community or campsite zone. Although the magnitude of change in bare ground did vary significantly with each of these factors, interactions between these factors were also statistically significant, making it necessary to conduct separate analyses for each plant community and for the sites camped on for one and three years.

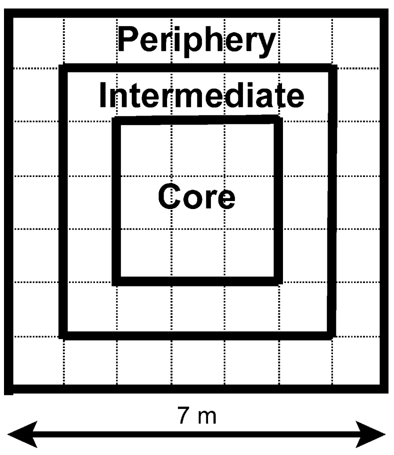

Fig. 1. Location of the quadrats that comprise the core, intermediate and periphery zones on each 49 m^2 campsite.

To assess response to chronic disturbance, we evaluated bare ground after each of three successive years of camping. In additional to differences between campsite zones, the effects of additional years of camping were tested using within-subject contrasts and effects of use intensity (one or four nights/year) were tested using between-subject contrasts. To assess recovery from acute disturbance, we evaluated bare ground after each of three successive years of recovery from a single season of camping. We also calculated yearly recovery as the difference in bare ground between successive years of recovery. We used repeated measures ANOVA to infer the significance of differences between campsite zones, years of recovery and use intensity. For all tests we used $\alpha = 0.05$.

4. Results

4.1. Response to chronic disturbance

On sites camped on for three successive years, bare ground typically increased with both nights/year and years of camping. The magnitude of impact was much more pronounced in the forest with *V. scoparium* understory than in the *D. cespitosa* meadow (Table 1). In the forest with *V. scoparium* understory, sites camped on for just one night experienced a 20% increase in bare ground. In the meadow, even sites camped on four nights/year for three successive years experienced a mean increase in bare ground of only 6%.

Although most of the variation in impact between campsites can be accounted for by variation in vegetation type, years of camping and nights of camping per year (Cole and Monz, 2004), there was substantial variation in impact among the four replicate campsites that received the same treatment. These differences presumably reflect uncontrolled variation in environment and camping behavior. Variability (between-site standard deviations, Table 1) was greater on forested sites than meadow sites. However, variation in impact between sites was positively correlated with amount of impact. Coefficients of variation (standard deviation divided by the mean) were higher on meadow sites. Meadow sites used four nights/year had higher coefficients of variation than sites used one night/year, while forest sites used one night/year had higher coefficients of variation than sites used four nights/year. Coefficients of variation were generally higher after the first and second year of camping than after the third year. This suggests that the precision of impact estimates at the scale of the entire campsite is lowest at levels of disturbance where bare ground is just becoming noticeable.

Within-site variability is much larger than between-site variability, particularly on the forested sites (Table 1). We used the standard deviation of change in bare ground, among the 49 quadrats, as our primary estimate of the spatial variability in impact on individual campsites.

Table 1
Mean change in bare ground, between-site variability and within-site variability for sites camped on for three successive years

	Meadow						Forest					
	1 night/year			4 nights/year			1 night/year			4 nights/year		
	1 yr	2 yr	3 yr	1 yr	2 yr	3 yr	1 yr	2 yr	3 yr	1 yr	2 yr	3 yr
Mean change in bare ground (%)	<1	6	5	-4	3	6	20	25	31	42	47	52
Between-site standard deviation (%)	1	5	1	5	6	7	9	8	10	7	8	9
Between-site coefficient of variation (%)	200	83	20	125	200	117	45	32	32	17	17	17
Within-site standard deviation (%)	4	7	5	5	9	9	27	26	24	25	25	21
Within-site coefficient of variation (%)	>500	152	113	324	272	>500	149	109	85	62	53	41

Significance of differences (repeated measures ANOVA, $\alpha = 0.05$); no inferential tests were conducted for between-site variability because there was no replication. Mean bare ground: meadow < forest; Meadow (1 night/yr = 4 nights/yr, 1 yr < 2 yr = 3 yr); Forest (1 night/yr < 4 nights/yr, 1 yr = 2 yr < 3 yr). Within-site s.d.: meadow < forest; Meadow (1 night/yr < 4 nights/yr, 1 yr < 2 yr = 3 yr); Forest (1 night/yr = 4 nights/yr, 1 yr = 2 yr > 3 yr). Within-site c.v.: meadow = forest; Meadow (1 night/yr = 4 nights/yr, 1 yr = 2 yr = 3 yr); Forest (1 night/yr > 4 nights/yr, 1 yr = 2 yr > 3 yr.

Standard deviations were substantially greater on sites in the forest with *V. scoparium* understory than they were on sites in the *D. cespitosa* meadow. Coefficients of variation did not differ significantly between vegetation types, however, ($F = 1.1$, $p = 0.34$). In the meadow, standard deviations increased significantly with years of camping ($F = 8.9$, $p < 0.01$) and they were significantly greater on sites camped on four nights/year than on sites camped on just one night/year ($F = 6.5$, $p = 0.04$). Coefficients of variation did not differ significantly with use intensity ($F = 0.9$, $p = 0.37$) or years of camping ($F = 1.1, p = 0.37$).

In the forest, in contrast, standard deviations were greatest after the first year of camping. Standard deviations after the second year were not significantly different from the first year ($F = 0.6$, $p = 0.47$); however, deviations were significantly lower after the third year of camping than after the second year ($F = 13.6$, $p = 0.01$). Coefficients of variation behaved similarly ($F = 2.5$, $p = 0.16$ and $F = 34.2$, $p = .001$, respectively). Standard deviations were not significantly different on sites used one and four nights/year ($F = 0.9$, $p = 0.38$). Coefficients of variation were significantly higher on sites used one night/year than on sites used four nights/year ($F = 13.2$, $p = 0.01$). Collectively, these results suggest that, at the scale of the campsite, spatial variability is greatest at intermediate impact levels.

4.2. Spatial pattern on campsites

On most sites there is a regular pattern of impact decreasing with distance from the center of the campsite (Fig. 2). This radial impact pattern is most pronounced at intermediate levels of groundcover disturbance. In the more resistant plant community (the *D. cespitosa* meadow), regular spatial variation is least pronounced at low use intensities (1 night/year of camping) and after initial use (one year of camping). In the less resistant plant community (the forest with *V. scoparium* understory), regular spatial variation is least pronounced after 3 years of the highest use intensity (4 nights/year of camping). We explored these regularities in spatial variation more rigorously by comparing the increase in bare ground in three concentric campsite zones (Fig. 1): core (nine quadrats at the center), intermediate (16 quadrats surrounding the core) and periphery (24 quadrats at the edge of the campsite).

In the *D. cespitosa* meadow, the first year of camping caused little groundcover disturbance in any of the zones (Fig. 3), so spatial variation was absent. Bare ground increased significantly ($F = 19.4$, $p < 0.01$) with successive years of camping and spatial variability was apparent after the second and third years of camping (Fig. 2). Bare ground decreased with distance from the center of the campsite (Fig. 3), although differences between zones were not statistically significant ($F = 0.1$, $p = 0.21$). Differences between sites camped on one night/year and four nights/year were not significant ($F = 0.2$, $p = 0.32$) and zone did not interact significantly with either nights/year or number of years of camping.

On sites in the forest with *V. scoparium* understory, the magnitude and extent of impact were much greater. Bare ground decreased significantly with distance from the center of the campsite ($F = 20.0$, $p < 0.01$). Each concentric zone had significantly less bare ground than the adjacent interior zone (Fig. 4). Increases in bare ground were significantly greater after each successive year of camping ($F = 30.3$, $p < 0.01$) and also on the sites camped on four nights/year ($F = 14.6$, $p < 0.01$). Campsite zone did not interact significantly with either nights/year or number of years of camping.

The time required both for substantial impact to occur and for near–maximum levels of impact to occur varied with plant community and use frequency, as well as between campsite zones. On meadow sites, substantial impact did not occur even in the core zone until the second year of camping. On meadow sites used one night/year, no additional impact or increase in spatial variation occurred with the third year of camping on any of the zones (Figs. 2 and 3). At this use frequency, in this plant community, two years of camping are required both to cause substantial impact and to reach near–maximum impact levels. On the sites used four nights/year,

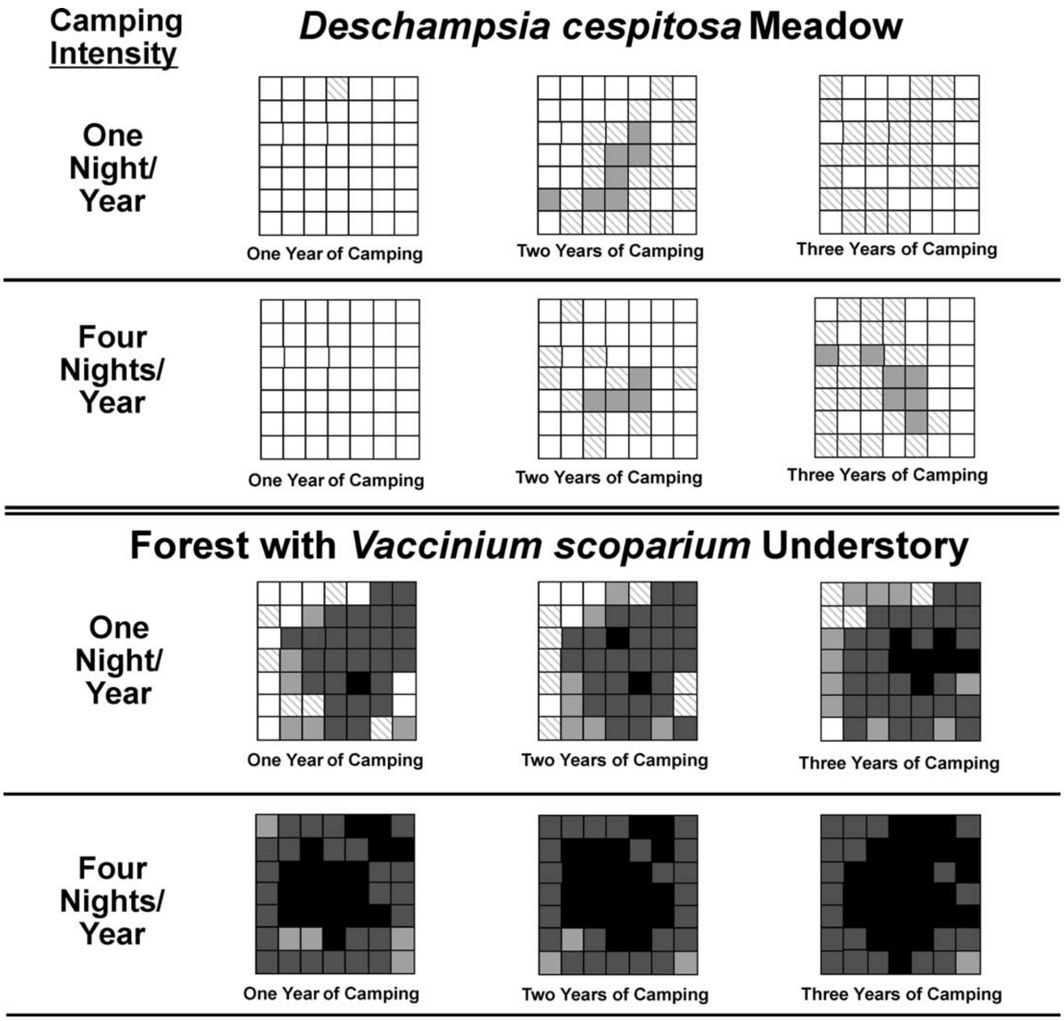

Fig. 2. Spatial patterns of groundcover disturbance on sites camped on for one, two and three successive years, at frequencies of either one night/year or four nights/year, in the *Deschampsia cespitosa* meadow and the forest with *Vaccinium scoparium* understory. Groundcover disturbance categories are: white ($<5\%$ increase in bare ground); light gray diagonal lines (5–10% increase); medium gray (10–20% increase); dark gray (20–50% increase) and black ($>50\%$ increase).

bare ground continued to increase with each additional year of camping in each of the zones, although only the increase in the intermediate zone was statistically significant. On these sites, the location of the most substantial increases in impact shifted outward from the core zone (after the second year of camping) to the intermediate zone (after the third year).

On sites in the forest with *V. scoparium* understory, substantial impact occurred the first year of camping in all zones, regardless of use frequency. In contrast to meadow sites, where near–maximum levels of impact occurred most rapidly where use intensity was lowest (one night/year sites and zones further from the core), near–maximum levels on forest sites occurred most rapidly where use intensity was greatest. Bare ground did not increase on the core of sites used four nights/year after the third year of camping (Figs. 2 and 4) and increases on the core of one night/year sites and the intermediate zone of four nights/year sites were not statistically significant. Bare ground was still increasing significantly after three successive years of camping on the intermediate zone of sites camped on one night/year and on the peripheral zone of all campsites.

4.3. Recovery from acute disturbance

As was the case for sites subjected to chronic disturbance, there was substantial variation in impact between sites recovering from a single year of camping. Most of the variation in impact between campsites can be accounted for by variation in vegetation type, years of recovery and nights of camping per year (Cole and Monz, 2004). Bare ground was minimal immediately after one year of camping on sites in the *D. cespitosa* meadow. Bare ground increased during the first year of recovery and small patches persisted for the entire three-year period over which recovery was assessed (Table 2). Although there was still substantial variation in impact among the four replicate

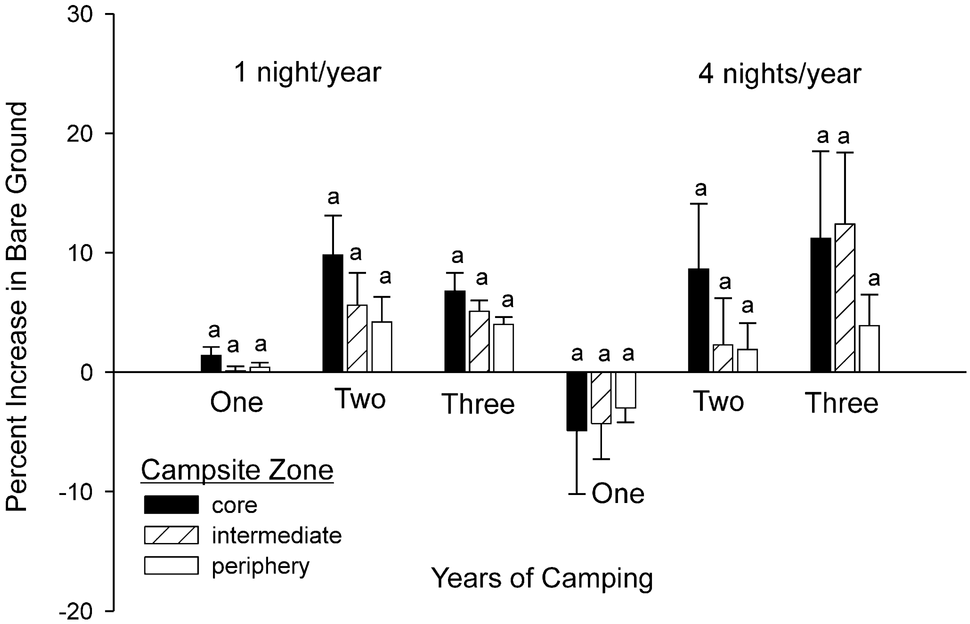

Fig. 3. Mean (1 SE) increase in bare ground on the core, intermediate and periphery zones of sites in the *Deschampsia cespitosa* meadow camped on for one, two and three years, at frequencies of either one night/year or four nights/year. Statistically significant differences between zones, for a given use frequency and number of years of camping, are denoted by different letters. Differences between years were statistically significant ($p < 0.01$), but differences in use frequency were not ($p = 0.32$).

campsites that received the same treatment, within-site variability was greater.

Spatial patterns of recovery within meadow sites were irregular, however (Fig. 5). Differences in bare ground between concentric zones were not statistically significant ($F = 0.9$, $p = 0.43$) and within-site variability (standard deviation and coefficient of variation of bare ground in the 49 quadrats) did not change significantly over the recovery period ($F = 2.5$, $p = 0.13$ for standard deviation; $F = 0.6$, $p = 0.56$ for coefficient of variation). This suggests

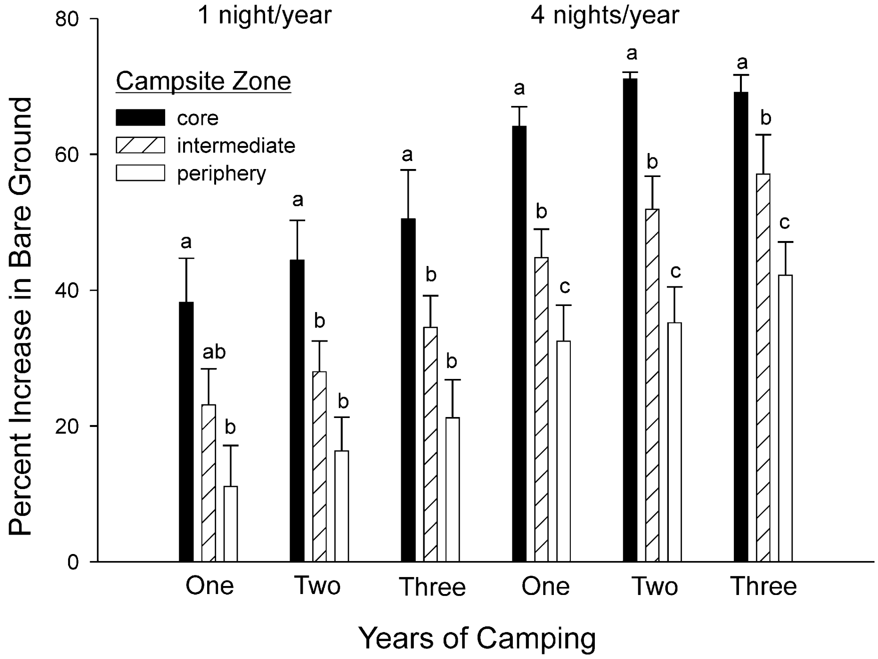

Fig. 4. Mean (1 SE) increase in bare ground on the core, intermediate and periphery zones of sites in the forest with *Vaccinium scoparium* understory camped on for one, two and three years, at frequencies of either one night/year or four nights/year. Statistically significant differences between zones, for a given use frequency and number of years of camping, are denoted by different letters. Differences between years were statistically significant ($p < 0.01$), as were differences in use frequency ($p < 0.01$).

Table 2
Mean change in bare ground, between-site variability and within-site variability for sites camped on for one season and then allowed to recover for three successive years

	Meadow						Forest					
	1 night/year			4 nights/year			1 night/year			4 nights/year		
	1 yr	2 yr	3 yr	1 yr	2 yr	3 yr	1 yr	2 yr	3 yr	1 yr	2 yr	3 yr
Mean change in bare ground (%)	7	4	4	7	4	4	18	13	16	33	32	24
Between-site standard deviation (%)	5	3	1	7	3	3	12	2	2	11	6	12
Between-site coefficient of variation (%)	75	75	25	100	75	75	67	15	13	33	19	50
Within-site standard deviation (%)	5	6	6	6	5	8	17	14	14	20	16	13
Within-site coefficient of variation (%)	100	194	158	114	231	597	106	109	88	61	52	73

Significance of differences (repeated measures ANOVA, $\alpha = 0.05$); no inferential tests were conducted for between-site variability because there was no replication. Mean bare ground: meadow < forest; Meadow (1 night/yr = 4 nights/yr, 1 yr = 2 yr = 3 yr); Forest (1 night/yr < 4 nights/yr, 1 yr = 2 yr = 3 yr). Within-site s.d.: meadow < forest; Meadow (1 night/yr = 4 nights/yr, 1 yr = 2 yr = 3 yr); Forest (1 night/yr = 4 nights/yr, 1 yr > 2 yr = 3 yr). Within-site c.v.: meadow > forest; Meadow (1 night/yr = 4 nights/yr, 1 yr = 2 yr = 3 yr); Forest (1 night/yr > 4 nights/yr, 1 yr = 2 yr = 3 yr).

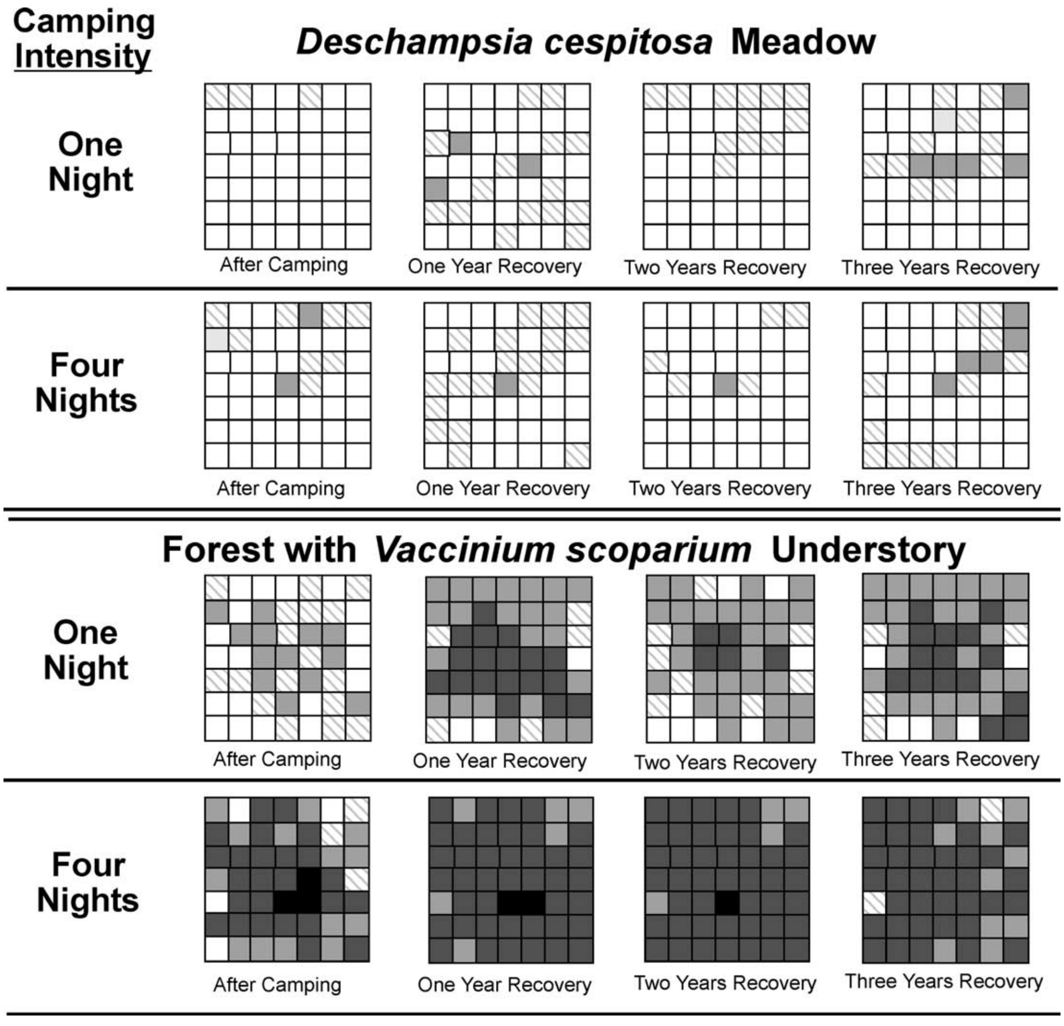

Fig. 5. Spatial patterns of groundcover disturbance on sites camped on either one night or four nights in the same year, in the *Deschampsia cespitosa* meadow and the forest with *Vaccinium scoparium* understory. From left to right, squares illustrate disturbance immediately after camping and after one, two and three years of recovery. Groundcover disturbance categories are: white (<5% increase in bare ground); light gray diagonal lines (5–10% increase); medium gray (10–20% increase); dark gray (20–50% increase) and black (>50% increase).

a shifting pattern of plant response unrelated to patterns of disturbance, although these patterns were perhaps initiated by the camping disturbance.

Impact was more dramatic on campsites in the forest with *V. scoparium* understory (Fig. 5), so more conclusions about recovery are possible. Again, between-site variation on sites that received the same treatments was smaller than within-site variation (Table 2). Within-site variation was regular, with bare ground decreasing with distance from the center of the campsite. Standard deviations did not differ significantly between sites camped on for one and four nights/year, but coefficients of variation were significantly higher on sites camped on for one night/year ($F = 9.1$, $p = 0.02$). Standard deviations and coefficients of variation decreased with successive years of recovery, but only the differences in standard deviation were statistically significant ($F = 5.5$, $p = 0.02$). Despite this decrease in variability over time, spatial patterns of impact remained after the three-year recovery period (Fig. 6). Bare ground varied significantly with zone ($F = 4.3$, $p = 0.01$) and zone did not interact significantly with either use intensity ($F = 0.05$, $p = 0.96$) or years of recovery ($F = 0.4$, $p = 0.82$).

Particularly on the sites camped on once, changes in bare ground were small and erratic over the three-year recovery period. We assessed the magnitude of yearly recovery by calculating the change in bare ground from one year to the next. Yearly recovery varied with zone, years of recovery, and use intensity, and zone interacted significantly with use intensity. Recovery was less pronounced on sites camped on just once ($F = 13.9$, $p < 0.01$). On these sites, recovery did not vary significantly between zones ($F = 1.4$, $p = 0.30$). On the sites camped on for four nights, recovery was significantly greater on the core of campsites than on the periphery ($p = 0.04$). Consequently, spatial variability had declined by the third year of recovery (Fig. 5).

Perhaps the most significant finding regarding recovery was that the magnitude of recovery was often positively related to the magnitude of impact. In the *D. cespitosa* meadow, the magnitude of the first year of recovery was significantly related to the increase in bare ground caused by camping (Pearson's $r = 0.51$), as was the magnitude of recovery over the entire three-year recovery period (Pearson's $r = 0.77$). In the forest with *V. scoparium* understory, the magnitude of the third year of recovery was significantly related to the increase in bare ground caused by camping (Pearson's $r = 0.62$), as was the magnitude of recovery over the three-year recovery period (Pearson's $r = 0.77$). Recovery rates decline as bare ground decreases, reaching minimal levels before bare ground reaches minimal levels. Consequently, complete recovery of these sites, particularly the forested ones, will take much more than three years.

4.4. Impact at different spatial scales

The regular radial pattern of impact on campsites means that estimates of the magnitude of impact will vary with the spatial scale of analysis. Estimates of camping impact decrease continuously as the scale of analysis is expanded. The mean increase in bare ground, on forested sites, after three years of camping for one night/year was 50% in

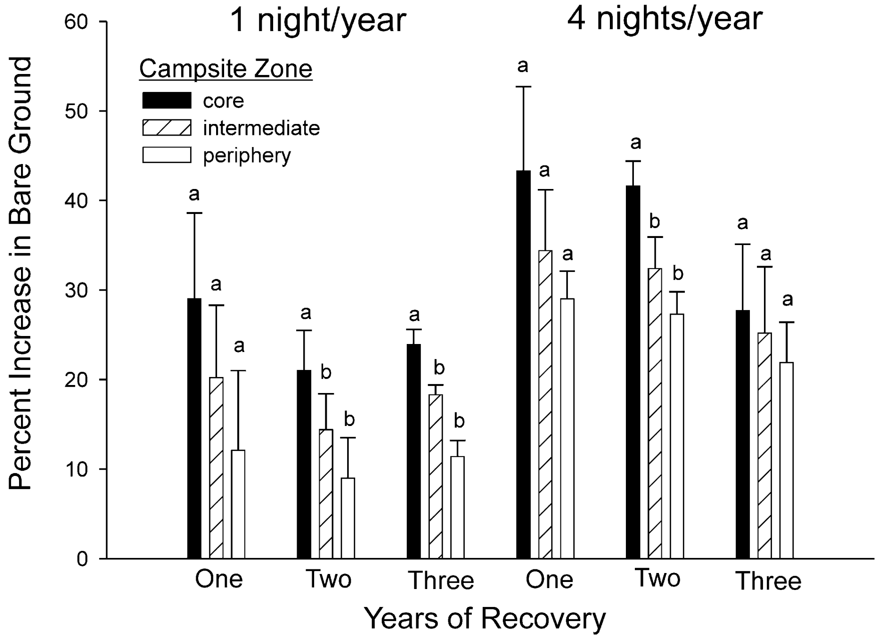

Fig. 6. Mean (1 SE) increase in bare ground on the core, intermediate and periphery zones of sites in the forest with *Vaccinium scoparium* understory camped on for one year, at frequencies of either one night/year or four nights/year, and allowed to recover for three years. Statistically significant differences between zones, for a given use frequency and number of years of recovery, are denoted by different letters. Differences between years were statistically significant ($p = 0.02$), as were differences in use frequency ($p < 0.01$).

the core zone. The mean increase for the entire 49 m^2 was only 30%. At the scale of the ≈ 5 ha stand in which these campsites are located, the estimate of bare ground resulting from camping would decline to ≈ 2%. At the scale of the Popo Agie Wilderness, estimates of bare ground resulting from camping would be negligible.

Variability in the magnitude of impact also varied with scale of analysis. On sites that experienced substantial impact, variability was greatest for within-campsite variation at the scale of the entire campsite. At both smaller and larger scales, variability was less pronounced. For example, on forest sites that were camped on for four nights/year for three years, the mean standard deviation for bare ground on all 49 quadrats on the campsite was 21% (Table 1). This is substantially higher that either the mean standard deviation for the core quadrats on these campsites (5%) or the standard deviation (between-site variation) for the four campsites that received this treatment (7%).

Finally, the spatial pattern of impact also varied with scale of analysis. Within any one of our campsite zones, variation in impact was probably random, reflecting random variation in the distribution of plants and of traffic on the site. At the scale of the entire campsite, impact is regularly distributed in a radial pattern. At the scale of the forest stand and meadow in which we conducted the experiments, impacted sites are points within a matrix of undisturbed area. At this scale, impacts were regularly distributed. Although we artificially generated this pattern, impact patterns at destination areas, such as around a lake or at a campground, are also likely to be regular, given the desire for some level of privacy. At the scale of the Popo Agie Wilderness, however, impacts are likely to be aggregated.

5. Discussion

The radial pattern of campsite zones that we found on our experimental campsites has been observed on actual campsites in national parks and wilderness areas (Stohlgren and Parsons, 1986; Leung and Marion, 1999b). Our data extend earlier work by documenting the development of this pattern in space and time. In a vegetation type as fragile as the forest with *V. scoparium* understory, this radial pattern can develop after a single night of camping and it can be sustained for more than three years after camping disturbance ceases (Fig. 6). The cause of this pattern is activity concentration close to the center of the site, in our case the result of the requirement that meals be cooked close to the center of the site. Our study only investigated spatial patterns within a 49 m^2 campsite, however. Further research is needed to investigate patterns of campsite impact over larger areas, scales at which site expansion can be problematic (Marion and Farrell, 2002).

Our results validate commonsense assumptions about camping behavior, as well as common interpretations of campsite impact studies. These assumptions were the basis for analytical models of campsites that Cole (1992) used to explore the relative influence of amount of use, vegetation fragility, vegetation density and activity concentration on vegetation loss on campsites. These models predict that the degree of activity concentration on individual campsites should have a substantial effect on the magnitude of vegetation loss. Vegetation loss should decline markedly as either the proportion of time spent in the central part of the site is increased or as the area within which activities occur is reduced. The models predict that the degree of spatial concentration should increase as use increases and that this tendency explains the empirically documented curvilinear relationship between amount of use and intensity of impact (Hammitt and Cole, 1998). The variation in amount of impact related to both amount of use and vegetation fragility should increase as amount of use decreases.

The spatial explicitness of our data also provides further insight into campsite impact processes. Prior research has established that groundcover disturbance increases over time as a result of increases in both the intensity of disturbance and the extent of disturbance (Cole and Hall, 1992; Leung and Marion, 2000). As Fig. 2 illustrates, however, both of these processes are limited and the limiting factors vary between the two plant communities and with use frequency. On the meadow sites camped on for one night/year, vegetation loss occurred after two years but the magnitude of loss equilibrated rapidly and at low levels (10% increase in bare ground). In this situation, groundcover disturbance is limited by the low intensity of disturbance associated with this use frequency. At higher use frequencies, both the intensity and extent of disturbance increase. Presumably, if use frequency was high enough, bare ground would be abundant and the intensity of disturbance would be limited by the size of the area in which most camping activities occurred. This suggests that where vegetation is resistant enough, campsites can be used repeatedly, at low use frequencies, without experiencing pronounced groundcover disturbance (Hammitt and Cole, 1998).

On the forest sites, a use frequency of just one night/year of camping causes substantial and immediate impact. Moreover, both the intensity and extent of impact increase with each successive year of camping. There is no evidence of equilibration, as there was on meadow sites. On the forest sites camped on for four nights/year, there is evidence that the intensity of disturbance had reached a limit ((75% increase in bare ground) on the campsite core after two years of use. It is also apparent from Fig. 2 that a limit to the extent of the most-disturbed quadrats is rapidly reached. Here it is the extent of disturbance, more than the intensity of disturbance that limits impact. This suggests that where vegetation is not resistant, it is virtually impossible to limit impacts through management of use frequency. Instead, impacts are most effectively limited through management of the spatial concentration of camping activities, as is suggested by Marion and Farrell (2002).

The finding that maximum regular spatial variability occurs at intermediate levels of use and disturbance appears consistent with Connell (1978) intermediate disturbance hypothesis and its application to recreational disturbance (Liddle, 1997). Diversity and variability is greatest at intermediate levels of recreation use and disturbance. Along with the finding that groundcover disturbance equilibrated at low impact levels and use frequencies on the meadow sites, this suggests that the relationship between amount of use and amount of impact is best approximated by a logistic function. The curve describing the use-impact relationship is initially exponential, becoming asymptotic at high use levels. Variation in use frequency has little effect on amount of impact both at very low and high use frequencies.

Although such a relationship has been suggested before (Hylgaard and Liddle, 1981; Cole, 1992), most studies have found an asymptotic relationship between use and impact (Leung and Marion, 2000). This probably reflects the methodology of most studies and, particularly, the range of use intensities that have been examined. Use levels must be very low and/or resistance must be very high to capture the portion of the curve below the threshold of rapidly increasing impact. Our study, by selecting a relatively resistant plant community (the *D. cespitosa* meadow), employing a low use frequency, assessing change over the entire campsite, and monitoring effects for several years, was successful in documenting this portion of the curve.

Another unexpected finding was the positive relationship between amount of disturbance and amount of recovery. Other studies have suggested that less impacted campsites are more likely to recover rapidly than sites that have been highly impacted (Cole and Hall, 1992). In our study, even the most highly disturbed experimental campsites were not disturbed repeatedly for many years, as is often the case in studies of established campsites. Consequently, impacts to underground root systems and the physical, chemical and biotic characteristics of the soil were probably not severe. Nevertheless, we were surprised that recovery rates declined to minimal levels long before percent bare ground approached pre-disturbance conditions. This suggests long recovery periods, even where impact levels are not that severe.

Our finding that variation in impact between campsites subjected to the same treatments was moderate has methodological implications. Variability was modest enough to allow us to draw conclusions about the influence of factors such as vegetation type and use intensity on bare ground, despite a small number of replicates (4). However, variability was substantial enough to make many predictions about the effect of a given treatment imprecise. For example, the increase in bare ground that occurred on forest sites camped on four nights/year for three successive years varied between 42 and 63%. This suggests that these experiments are most helpful in evaluating the relative influence of various factors. For predictive purposes, experiments should incorporate a larger number of replicates.

These results have several practical management implications. The profound difference between these two plant communities, in susceptibility to camping impact, illustrates the importance of campsite selection as a means of limiting impact. A single night of use in the forest caused substantial impact (a mean 20% increase in bare ground), while meadow sites used four night/year for three years experienced little impact (a mean 6% increase in bare ground). Everything else being equal, vegetation impact can be reduced if groups are advised to camp in the meadow rather than the forest. Our data also allow for approximate estimates of the vegetation impact likely to be caused by low levels of camping. However, this impact was caused by campers practicing Leave No Trace techniques (Hampton and Cole, 1995); most groups will cause much more impact.

These results also have implications regarding the appropriateness of containment and dispersal campsite management strategies. The containment strategy—in which visitors are asked or required to camp on established or designated campsites—is generally the most effective way to limit campsite impact (Cole, 1981; Marion and Farrell, 2002). Dispersal—in which campers are encouraged to spread out and camp on undisturbed sites—will only be effective where use intensities are low, vegetation types are durable, and campers practice Leave No Trace techniques (Cole and Fichtler, 1983). Dispersal is clearly a more viable option in the meadow than in the forest. In the meadow, impacts could be unnoticeable (dispersal could be effective) even in situations where the same portion of the meadow was camped on for one or two nights per year. In the forest, since a single night of camping causes substantial impact, dispersal is likely to aggravate impact problems, even at low use levels. These forested sites probably need to be camped on less than once every ten years if they are to avoid becoming established campsites. The primary caveat to this is that a highly committed Leave No Trace camper can keep impact to minimal levels even in the forest. Vegetation impact in these forests can be minimal if campers cook with stoves on rock outcrops, sleep on naturally barren ground, and watch their feet to avoid trampling plants when walking.

6. Conclusion

The spatially and temporally explicit results of this experimental study increase the precision of our understanding of campsite disturbance processes. This new perspective increases our confidence in commonsense assumptions about camping behavior and interpretations of the results of campsite impact studies. Camping activities are concentrated close to the center of the campsite. This creates a radial pattern of impact that develops quickly and can remain long after camping disturbance ceases. This pattern is most pronounced at intermediate levels of use and impact. Our results validate the management implications developed from earlier studies, particularly related to the importance of impact concentration as a campsite management strategy (Marion and Farrell, 2002). They demonstrate that even when practicing low-impact techniques, infrequent camping can cause substantial impact. Conversely, impact levels can be quite low when Leave No Trace camping is practiced in resistant plant communities (Hampton and Cole, 1995). Finally, they emphasize the profound effect of scale of analysis on estimates of the magnitude, variability, and pattern of camping impact. Since conclusions about the significance of recreation impact will vary with the scale of analysis, it is important to carefully match the scale of analysis to the objectives of any study of recreational impact, including monitoring efforts. Studies that evaluate impact at multiple scales are likely to be particularly insightful.

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