RESEARCH

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Impacts of Camping on Vegetation: Response and Recovery Following Acute and Chronic Disturbance

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ABSTRACT / Experiments with controlled levels of recreational camping were conducted on previously undisturbed sites in two different plant communities in the subalpine zone of the Wind River Mountains, Wyoming, USA. The plant communities were coniferous forest with understory dominated by the low shrub *Vaccinium scoparium* and a riparian meadow of intermixed grasses and forbs, of which *Deschampsia cespitosa* was most abundant. Sites were camped on at intensities of either one or four nights per year, for either one (acute disturbance) or three consecutive years (chronic disturbance). Recovery was followed for three years on sites camped on for one year and for one year on sites camped on for three years. Reductions in vegetation cover and vegetation height were much more pronounced on sites in the forest than on sites in the meadow. In both plant communities, increases in vegetation impact were not proportional to increases in either years of camping or nights per year of camping. Close to the center of campsites, near-maximum levels of impact occurred after the first year of camping on forested sites and after the second year on meadow sites. Meadow sites recovered completely within a year, at the camping intensities employed in the experiments. Forest sites, even those camped on for just one night, did not recover completely within three years. Differences between acute and chronic disturbance were not pronounced.

Recreation and tourism are among the foremost threats to the mountains of the world. Particularly in wilderness, national parks, and other protected areas, where preservation of natural conditions is of primary importance, the biophysical impacts of recreation and tourism present a formidable management challenge (Manning and others 1996). In many wilderness areas, recreationists are allowed to travel and camp overnight virtually wherever they wish. In such places, the impacts of camping can be both locally severe and widespread (Hendee and Dawson 2002).

Campsite conditions have been studied since at least the early 1960s (Frissell and Duncan 1965), and much is known about the response of vegetation and soil to camping. Groundcover vegetation is injured and often eliminated, while soils are compacted, biologically and chemically altered, and even eroded (Leung and Marion 2000). Since the early 1980s, data from campsite impact studies has been used to assess the efficacy of alternative campsite management strategies. Particularly helpful in this regard have been studies of the factors that influence the magnitude of campsite impacts. As originally described in Cole (1987), magnitude of impact is the product of both the intensity of impact per unit area and the spatial extent of impact. Intensity is largely a function of (1) amount and/or frequency of use, (2) the types and behaviors of users, (3) season and/or time of use, and (4) the durability of the site where camping occurs. Spatial extent is a direct reflection of the spatial distribution of camping.

In most studies, the influence of these variables has been assessed by comparing magnitude of impact on campsites that vary, for example, in amount of use or in the plant community on which camping occurs (Marion and Cole 1996). Such studies have the advantage of realism but are disadvantaged by the difficulty of controlling other influential factors (e.g., visitor behavior) or even obtaining precise estimates for independent variables (e.g., amount of use). Nevertheless, such studies have consistently shown that (1) there is an asymptotic relationship between amount of use and amount of impact, with relatively low levels of use causing substantial impact and (2) the impact of a given amount of use varies greatly between sites with different plant communities, soil characteristics and topography (Leung and Marion 2000).

KEY WORDS: Campsites; Ecological impact; Recreation ecology; Resistance; Vegetation impact; Wilderness

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Perhaps the ideal compromise between realism and the ability to control influential variables would be experimental applications of camping stress. Such an approach could focus on initial applications of relatively low use levels, where amount of use and site durability are likely to be particularly influential explanatory variables. Numerous experimental trampling studies, conducted since the pioneering work of Wagar (1964), provide more precise estimates of the use–impact relationship and the durability of different vegetation types (see Liddle 1997, Leung and Marion 2000, Newsome and others 2002 for recent reviews). However, experimental camping studies are virtually nonexistent. Bogucki and others (1975) and Leonard and others (1983) quantified the effects of a known amount of camping on previously unused sites, but neither of these studies were manipulative experiments (sensu Hurlbert 1984) with random assignment of different treatments to replicated experimental units.

Cole (1995a) reports the results of a true camping experiment, conducted in four different plant communities. Results of this study were generally consistent with those from studies of established campsites and provided more precise estimates of how campsites respond to low levels of camping stress. However, there were a number of limitations to the study. Treatments were applied by researchers rather than by recreational campers. Treatments were only applied for one year and only one year of recovery was assessed. Gniesser (2000) describes the response of five different tundra plant communities to two nights of camping by researchers. He also assessed conditions both immediately after camping and one year later, but only on the area underneath the tent.

The motivation for the study described in this paper was to conduct camping experiments that were more realistic and that offered more insight into temporal patterns of response. Specifically, we quantified the magnitude of vegetation impact caused by recreational campers well versed in low impact camping techniques, on previously undisturbed sites in two physiognomically distinct plant communities. These experimental campsites were subjected to two use intensities, both indicative of light use (one and four nights per year of camping). Because recreational impacts can vary at different spatial scales (Taylor and others 1993), we quantified camping effects both close to the center of the campsite and at the scale of the entire campsite. As suggested by Bender and others (1984), we studied response to both acute (1 year of camping) and chronic (3 years of camping) disturbance. We examined short-term resilience (< 1 year) of chronically disturbed vegetation and the longer-term (3 year) recovery of vegetation subjected to a single season of disturbance.

Study Area

The camping experiments were conducted in the Wind River Mountains of northwestern Wyoming. Over 400,000 ha of land in the Wind River Mountains are protected in three contiguous Forest Service wilderness areas, the Bridger, Fitzpatrick, and Popo Agie, and a portion of the Wind River Indian Reservation that is managed as de facto wilderness. Although not as world-renowned as nearby Yellowstone and Grand Teton national parks, these wildernesses are heavily used by backpackers and horse packers. Heavy use leaves many places devoid of vegetation and often with serious erosion problems. Many of the most severe impacts are in the subalpine zone, which is noted for outstanding scenery and abundant lakes.

Experiments were conducted in two plant communities that (1) were 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. The sites were located about 3 km apart, in the watersheds of Stough and Basco Creeks, headwater tributaries of the Middle Fork of the Popo Agie River, in the Popo Agie Wilderness. One plant community, located at an elevation of 3100 m, was a subalpine coniferous forest with groundcover dominated by the low-growing shrub, *Vaccinium scoparium.* Forest canopy cover was about 20%. *Pinus contorta* and *Pinus albicaulis* were the most abundant mature tree species, although *Picea engelmannii* and *Abies lasiocarpa* were common in flats where thicker soils accumulate. About 80% of the tree reproduction was *Pinus albicaulis,* although *Abies lasiocarpa* was also reproducing consistently. Understory vegetation was low-lying and discontinuous, with substantial exposed rock and litter between plants. *Vaccinium scoparium* accounted for more than 90% of the groundcover vegetation, with *Erigeron peregrinus, Arnica cordifolia,* and *Hieracium gracile* the most widely distributed and abundant associates. Mean groundcover vegetation cover was 78% and mean height was 8.6 cm.

The second plant community, located at an elevation of 3125 m, is a riparian meadow surrounded by subalpine forest. Such meadows, while wet immediately after snowmelt, dry as summer progresses and become prime sites for camping. This meadow contained a dense, diverse assemblage of graminoids and forbs. Forbs were more abundant than graminoids. The most abundant forbs, *Antennaria corymbosa, Caltha leptosepala,* and *Potentilla diversifolia,* were matted or had mostly basal leaves. Caespitose graminoids, *Deschampsia cespitosa, Agrostis humilis, Phleum alpinum, Juncus drummondii,* and various species of *Carex,* were all common. There were no shrubs. Mean groundcover vegetation cover was 92% and mean height was 3.8 cm.

These experiments were conducted as part of a larger study of trampling and camping impacts in the Wind River Mountains. Further information on the species composition of these plant communities and their response to experimental trampling can be found in Cole and Monz (2002).

Methods

In each of these two plant communities we located 16 potential campsites and four control sites in places with no evidence of previous recreation use. Potential campsites were selected on the basis of being undisturbed, flat, at least 49 m^2 in size, with relatively homogeneous vegetation similar in composition to that of the other campsites. Each potential campsite was a square, 7 m on each side. Its location was denoted by short stakes in each corner and at the center of the site. Criteria for controls were similar, except that they could be substantially smaller. In each plant community, campsites and controls were spread over an area of approximately 5 ha.

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 sites, four sites were camped on one night per year, while the others were camped on four nights per year. To the extent possible, the timing of use within a year, on sites camped on four nights per 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 several of the experimental campsites. They were instructed to drop their backpacks, set up their tent anywhere within the 49 m^2 campsite and to set up their cooking stove 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. NOLS courses emphasize Leave No Trace techniques (Hampton and Cole 1995) for minimizing the impacts associated with recreation use. 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.

Data Collection

On each campsite, measurements were taken both close to the center, where impact should be most pronounced, and across the entire 49-m^2 site. The central portion of the campsite was sampled with four 30 × 50-cm quadrats, located 0.25–0.75 m from the center point and bisected by transects between the center and each of the four corners. In each of these quadrats we estimated percent cover of vegetation by measuring the cover of its inverse—bare ground. Bare ground is 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%. The assessment of the entire campsite was conducted by laying out a rope grid that divided the site into 49 1-m^2 quadrats. In each quadrat we estimated percent cover of bare ground, using the same cover classes listed above.

To estimate vegetation height, we used a point quadrat frame with 5 pins, each pin located 5 cm from the next pin. Vegetation height was only measured in the subplots close to the campsite center. The frame was placed 10 times, systematically, along the length of each subplot. Pins were dropped to the ground. When the pin hit live vegetation, the height of the pin strike was recorded to the nearest 1 cm. If the pin hit a live plant at less than 0.5 cm, 0.2 cm was recorded. When no living plants were hit, 0 was recorded.

Stakes were placed in the center of each of the four control sites. On each control, four 30- × 50-cm quadrats were established 0.5–1.0 m from the center stake, on transects oriented in each of the cardinal directions from the center. Control measures were identical to those taken in the central portion of each campsite.

Initial measurements were taken on each of the 16 campsites and four controls in each of the two plant communities within a week before the commencement of camping treatments. Posttreatment measurements were taken within a week after the last night of camping. This research design, in which measurements are taken before and after treatment, on both controls and campsites, was necessary to account for pretreatment differences between the campsites. The campsites that were camped on for three consecutive years were measured before and after camping for each of those years, as well as one year after the final camping treatment. This permitted an assessment of the effect of chronic disturbance (successive years of camping), as well as the magnitude of seasonal recovery (the amount of recovery that occurred during the year between camping treatments) and the effect of successive years of camping on seasonal recovery. The campsites that were camped on for one year were measured before and after camping in year one and once per year for the following three years. These data were used to assess longer-term recovery over the three years that followed an acute disturbance event (a single year of camping). Control plots were also measured twice per year for the first three years of the experiment and once in the final year.

Data Analysis

Vegetation cover was calculated by subtracting percent bare ground from 100%. Mean vegetation height was calculated by summing the heights of the 50 pin hits in each quadrat and dividing by the number of nonzero values. For the central portion of the site and on controls, vegetation cover and height estimates from the four quadrats were combined in a single mean measure. Vegetation cover estimates from the 49 quadrats covering the entire campsite were also combined in a single mean measure. Thus there were four replicates of each treatment in each plant community.

For vegetation cover and height we present unadjusted measures to illustrate the spatial variability in conditions prior to treatment, as well as the temporal variability exhibited on the controls. Most analyses, however, are based on synthetic variables of change that account for both the original variation between sites and changes that occurred on controls. Relative vegetation cover (*RVC*) is the proportion of the original vegetation cover that remains after camping, adjusted for changes on controls (Bayfield 1979). From measures of (1) initial cover on campsites (I_{camp}), (2) posttreatment cover on campsites (P_{camp}), (3) initial cover on controls ($I_{control}$), and (4) posttreatment cover on controls ($P_{control}$),

$$RVC = [(P_{camp} \div I_{camp}) \div (P_{control} \div I_{control})] \times 100\% \quad (1)$$

An *RVC* value of 100% would suggest that there was no change in cover that could be attributed to camping disturbance. Relative vegetation height (*RVH*) is calculated in an analogous manner, substituting mean height values for the cover values in equation 1.

We used repeated measures ANOVA (GLM Repeated Measures, SPSS, Ver 9.0) for all our inferential statistical analyses. First, we assessed whether the magnitude of vegetation response to camping varied with years of camping, nights of camping per year, or plant community. Vegetation response (both relative vegetation cover and relative vegetation height) did vary significantly with each of these factors. However, interactions between these factors were also statistically significant, making it necessary to conduct separate analyses for each plant community and for the acute (1 year) and chronic (3 year) camping disturbance experiments.

In the chronic disturbance experiment, we were interested in whether camping caused vegetation impact and whether the magnitude of impact varied with years of camping or with use intensity (one or four nights per year). We considered vegetation impacts to be significant when Dunnett's tests, comparing controls with campsites, were significant. We used the repeated type of within-subject contrasts in the GLM repeated-measures procedure to compare differences in vegetation impact between successive years of camping (e.g., does a second year of camping cause more impact than the first year). We used the repeated type of between-subject contrasts to compare sites that received four nights per year of camping with those that were camped on one night per year.

Sites camped on for three successive years had about 11 months to recover between camping treatments. For these sites, we calculated seasonal recovery as the difference in relative vegetation cover (*RVC*) or height (*RVH*) immediately after camping and after the 11-month recovery period (immediately before the next year of camping), as a proportion of the change resulting from camping. Seasonal recovery of vegetation cover (*SRVC*) was calculated as follows:

$$SRVC = (RVC \text{ after recovery} - RVC \text{ after camping}) \div (100 - RVC \text{ after camping}). \quad (2)$$

Where camping caused no cover loss (i.e., *RVC* after camping ≥ 100%), we assigned a value of 100% to *SRVC*. Seasonal recovery of vegetation height (*SRVH*) was calculated in an analogous manner. We used repeated type within-subject and between-subject contrasts to assess variation in seasonal recovery with successive years of camping and use intensity, respectively.

In the acute disturbance experiment, we were interested in the rate of recovery after disturbance was cur-

Table 1. Vegetation cover and height near the center of meadow and forest sites camped on for three successive years[a]

	First year		Second year		Third year		One year recovery
	Before	After	Before	After	Before	After	
Vegetation cover (%)							
Meadow							
Control	97 (1)	98 (1)	92 (2)	94 (1)	98 (1)	98 (2)	94 (3)
One night per year	95 (2)	94 (2)	88 (2)	84 (3)	93 (1)	91 (2)	93 (1)
Four nights per year	90 (2)	91 (4)	85 (2)	76 (4)	89 (2)	78 (2)	80 (5)
Forest							
Control	77 (4)	79 (5)	71 (8)	72 (8)	82 (7)	80 (7)	81 (8)
One night per year	72 (5)	46 (14)	28 (9)	26 (10)	38 (6)	28 (5)	34 (6)
Four nights per year	80 (6)	43 (3)	4 (2)	5 (2)	18 (3)	5 (1)	10 (3)
Vegetation height (cm)							
Meadow							
Control	4.6 (0.2)	3.6 (0.1)	3.2 (0.2)	4.4 (0.3)	4.1 (0.6)	5.5 (0.6)	4.0 (0.5)
One night per year	3.8 (0.9)	2.1 (0.3)	2.4 (0.3)	2.4 (0.3)	2.9 (0.5)	2.8 (0.5)	3.2 (0.4)
Four nights per year	3.2 (0.6)	1.8 (0.2)	2.2 (0.3)	1.5 (0.2)	2.5 (0.3)	1.5 (0.1)	3.1 (0.3)
Forest							
Control	10.0 (0.9)	9.1 (0.3)	8.3 (0.8)	8.5 (0.5)	9.1 (0.9)	9.3 (0.8)	8.7 (1.0)
One night per year	6.6 (0.8)	6.0 (0.9)	2.4 (0.9)	2.4 (0.9)	2.5 (0.5)	2.2 (0.7)	3.1 (0.2)
Four nights per year	10.3 (0.9)	7.2 (0.9)	0.4 (0.4)	0.5 (0.3)	1.8 (0.2)	0.8 (0.1)	1.8 (0.2)

[a]Data are mean (1 SE), $N = 4$, before and after each year of camping, as well as after a final year of recovery, on controls and on sites camped on for one night/year and four nights/year.

tailed. We used repeated type within-subject and between-subject contrasts to assess the variation in vegetation response (relative vegetation cover and relative vegetation height) resulting from successive years of recovery and variation in use intensity, respectively. We were also interested in how many years were required for vegetation to completely recover. Recovery was considered complete when the relative vegetation cover and relative vegetation height on campsites were not significantly different from cover and height on controls (Dunnett's test).

Figures below show results for each plant community and treatment separately. The statistical significance of differences between treatments within each plant community, depicted in the graphs, was assessed using univariate ANOVA and Duncan's multiple comparisons test. There are some slight differences between the results of the repeated measures analyses (our primary tool for statistical inference) and the univariate analyses (presented for graphic purposes). For all tests we used $\alpha = 0.05$.

Results

Effects of Three Years of Camping

Both vegetation cover and height declined with successive years of camping in both plant communities (Table 1). However, conditions on controls also changed over the four-year experimental period and substantial variability between sites existed prior to camping. Variability was greater for vegetation height than for vegetation cover and was greater in the forest than in the meadow. To statistically control these two sources of variability, further analyses relied on the synthetic indices of change, relative vegetation cover and relative vegetation height.

Although camping reduced vegetation cover close to the center of campsites in both plant communities, effects were much less pronounced in the *Deschampsia cespitosa* meadow (Figure 1). On meadow sites, relative vegetation cover varied with years of camping ($F = 9.2$, $P < 0.01$) and with nights per year of camping ($F = 2.9$, $P = 0.05$), but the interaction between years and nights per year was also significant ($F = 3.8$, $P = 0.02$). One night per year of camping had little effect; relative vegetation cover on meadow sites camped on one night per year was not significantly different from controls after one, two, or three years of camping ($P = 0.08$–0.49). Sites camped on one night per year for three successive years still had 95% of the vegetation cover expected had they never been camped on (i.e., relative vegetation cover was 95%). Meadow sites camped on for four nights per year did experience a significant decline in relative vegetation cover after the second and third years of camping ($P = 0.05$ and < 0.01, respectively). On these sites, relative vegetation cover

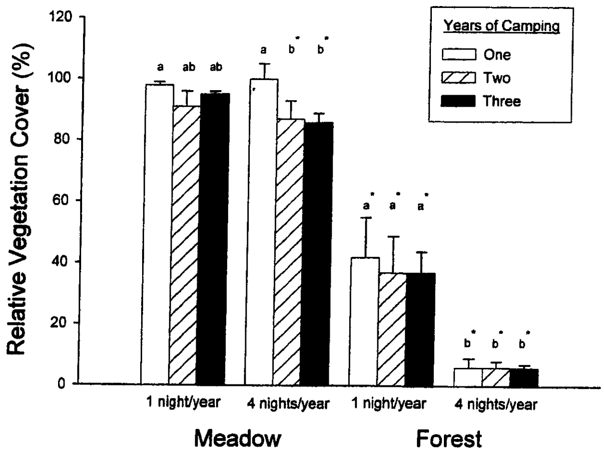

Figure 1. Relative vegetation cover (mean + 1 SE), near the center of meadow and forest sites, after one, two, and three years of camping at intensities of one and four nights per year. Within each plant community, treatments with the same letter are not significantly different ($\hat{\alpha}$ = 0.05). *Treatments differ from controls.

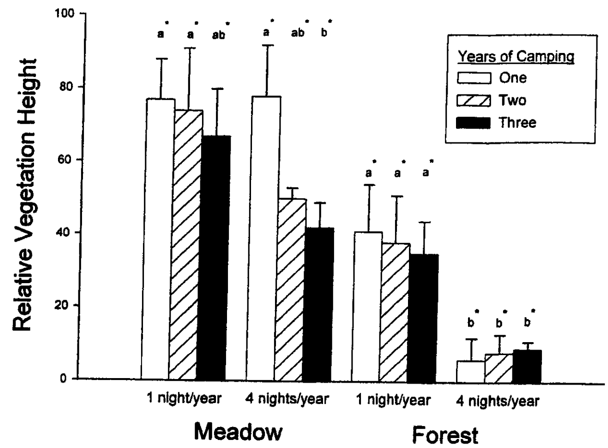

Figure 2. Relative vegetation height (mean + 1 SE), near the center of meadow and forest sites, after one, two, and three years of camping at intensities of one and four nights per year. Within each plant community, treatments with the same letter are not significantly different ($\hat{\alpha}$ = 0.05). *Treatments differ from controls.

was significantly less after two years of camping than after one (F = 16.9, P = 0.03), but the third year of camping caused no further loss of cover (F = 0.0, P = 0.88). Even after three successive years of camping, the central portion of sites used four nights per year still had relative vegetation cover of 86%.

Our analysis differed slightly for sites in the forest with *Vaccinium scoparium* understory. When initially subjected to trampling disturbance, *Vaccinium scoparium* shrubs experience what has been called "delayed damage" (Bayfield 1979). Although little damaged immediately after a disturbance event, they experience substantial dieback during the subsequent winter. Consequently, as was found in our study of trampling in this plant community (Cole and Monz 2002), vegetation cover declined on campsites (instead of increasing) over the "recovery" period between the end of the first year of camping and the beginning of the second year of camping (Table 1). Consequently, the most accurate measure of the effect of one season of camping, in this plant community, is relative vegetation cover immediately before the beginning of the second year of camping. This is the measure shown in Figure 1. For the effects of two and three seasons of camping, we report cover immediately after camping.

In contrast to the meadow, camping had a profound effect on the vegetation cover of sites in the forest. Mean relative vegetation cover on sites camped on for a single night was just 42% (Figure 1). Whether use intensity was one or four nights per year, relative vegetation cover did not vary significantly with successive years of camping (F = 0.2, P = 0.84). The first year of camping caused about as much impact as three successive years of camping. Sites camped on for four nights/year had significantly less cover than sites used one night/year, regardless of the number of years of camping (F = 38.7, P < 0.01). Consequently, four nights of camping in one year caused substantially more cover loss than a single night of camping for three successive years.

In the *Deschampsia cespitosa* meadow, camping reduced vegetation height more substantially than vegetation cover. Mean relative vegetation height after a single night of camping was 77% in the central portion of the site (Figure 2). Relative vegetation height varied with years of camping (F = 3.9, P = 0.04) and with nights/year of camping (F = 5.8, P = 0.02). Each successive year of camping caused a further decrease in vegetation height. Differences between sites camped on one and four nights per year were most pronounced after the second and third years of camping.

In the forest with *Vaccinium scoparium* understory, the effect of camping on vegetation height was similar to its effect on cover (Figure 2). Relative vegetation height varied significantly with nights per year of camping (F = 38.4, P < 0.01) but not with successive years of camping (F < 0.01, P < 0.98). The vegetation on sites camped on for four nights per year was significantly shorter than on sites used one night per year and, regardless of whether use intensity was one or four nights per year, the first year of camping caused about as much impact as three successive years of camping.

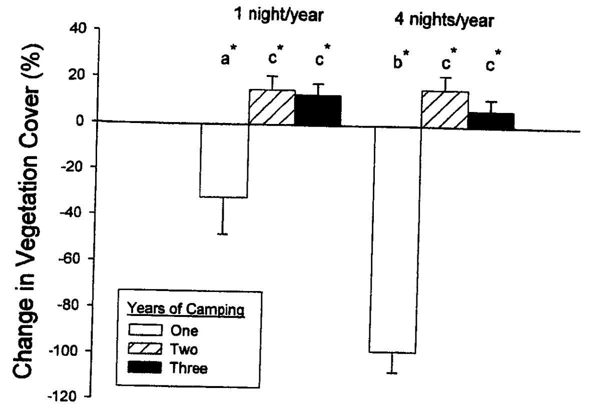

Figure 3. Recovery of vegetation cover near the center of forest sites in the year following the first, second, and third years of camping at intensities of one and four nights per year. Values are increase in relative cover (mean + 1 SE) during the year of recovery as a proportion of loss in cover as a result of camping. Treatments with the same letter are not significantly different ($\alpha = 0.05$). *Treatments differ from controls after recovery.

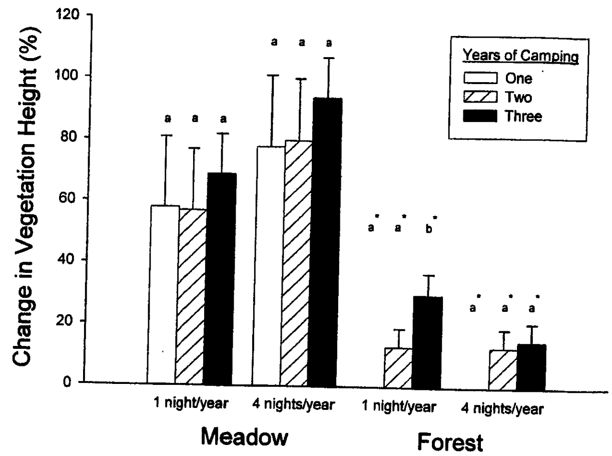

Figure 4. Recovery of vegetation height near the center of meadow and forest sites in the year following the first, second, and third years of camping at intensities of one and four nights per year. Values are increase in relative height (mean + 1 SE) during the year of recovery as a proportion of loss in height as a result of camping. Within each plant community, treatments with the same letter are not significantly different ($\alpha = 0.05$).

Seasonal Recovery with Chronic Camping Disturbance

In the *Deschampsia cespitosa* meadow, camping caused significant decreases in vegetation cover only after two and three successive years of camping at intensities of four nights per year. Even on these sites, mean relative cover was almost 90%. Consequently, for this parameter and plant community, little can be learned about how chronic disturbance (successive years of camping) influences the short-term resilience (seasonal recovery) of the plant community.

In the forest with *Vaccinium scoparium* understory, camping reduced cover greatly and subsequent recovery was slow. Seasonal recovery of vegetation cover varied with years of camping ($F = 8.0$, $P < 0.01$). Recovery after the first year of camping was significantly less than that after the second and third years (Figure 3). However, as noted previously, the explanation for lack of recovery after the first year is that death of many of the injured *Vaccinium* shrubs did not occur until winter. Although the magnitude of recovery after the third year of camping is less than it is after the second year, this difference is not statistically significant ($F = 2.2$, $P = 0.10$). Recovery on sites camped on for one night per year was significantly greater than recovery on sites camped on for four nights per year ($F = 9.8$, $P = 0.01$). Thus the evidence that more frequent use decreases short-term resilience is more substantial than evidence that resilience declines with chronic disturbance (successive years of camping).

Since vegetation height declined substantially in both plant communities, it was possible to assess the effects of successive years of camping on short-term recovery of vegetation height in both communities (Figure 4). In the meadow, seasonal recovery of vegetation height did not vary significantly with either nights/year of camping ($F = 0.8$, $P = 0.40$) or number of years of camping ($F = 1.4$, $P = 0.28$). After each recovery period, regardless of use intensity or years of camping, relative vegetation height on campsites was not significantly different from relative vegetation height on controls ($F = 0.6$, $P = 0.28$). Although this suggests near-complete recovery, mean recovery was not 100% for any of the treatments (Figure 4).

In the forest, little recovery of vegetation height occurred (Figure 4). Seasonal recovery varied significantly with years of camping ($F = 23.5$, $P < 0.01$) but interaction with nights per year was also significant ($F = 5.8$, $P = 0.02$). Further analysis shows that recovery increased after each successive year of camping on all sites. However, on sites used one night per year, only the difference between the second and third recovery periods was significant ($F = 25.6$, $P = 0.04$) and on sites used four nights per year, only the difference between the first and second recovery periods was significant ($F = 21.7$, $P = 0.02$). Differences between sites camped on one and four nights per year were not significant after any of the recovery periods ($F = 0.1$–0.9, $P = 0.14$–0.45).

Table 2. Vegetation cover and height near the center of meadow and forest sites camped on one year and then allowed to recover for three years[a]

	One year of camping		Years of recovery		
	Before	After	One	Two	Three
Vegetation cover (%)					
Meadow					
Control	97 (10)	98 (1)	94 (1)	98 (2)	94 (3)
One night per year	93 (2)	91 (1)	85 (5)	88 (2)	85 (2)
Four nights per year	82 (3)	86 (4)	78 (3)	87 (4)	85 (3)
Forest					
Control	77 (4)	79 (5)	72 (8)	80 (7)	81 (8)
One night per year	84 (4)	74 (2)	47 (13)	67 (8)	71 (5)
Four nights per year	78 (3)	26 (3)	26 (9)	38 (3)	47 (5)
Vegetation height (cm)					
Meadow					
Control	4.6 (0.2)	3.6 (0.1)	4.4 (0.3)	5.5 (0.6)	4.0 (0.5)
One night per year	3.1 (0.5)	1.6 (0.2)	2.8 (0.4)	2.9 (0.4)	2.1 (0.2)
Four nights per year	3.3 (0.3)	1.8 (0.3)	3.1 (0.2)	4.3 (0.3)	3.3 (0.3)
Forest					
Control	10.0 (0.9)	9.1 (0.3)	8.5 (0.5)	9.3 (0.8)	8.7 (1.0)
One night per year	10.1 (0.9)	8.2 (0.7)	4.9 (1.1)	4.9 (1.0)	4.8 (0.9)
Four nights per year	4.5 (0.7)	2.6 (0.4)	1.4 (0.5)	2.2 (0.2)	2.9 (0.3)

Data are mean (1 SE), $N = 4$, before and after the year of camping, as well as after each of the three recovery years, on controls and on sites camped on for one night/year and four nights/year.

Longer-Term Recovery from Acute Camping Disturbance

The sites that were camped on for one year (acute disturbance) and then allowed to recover for three years also had variable vegetation cover and, particularly, vegetation height prior to disturbance (Table 2). Consequently, analyses are based on response of the synthetic indices of change, relative vegetation cover, and height. In the *Deschampsia cespitosa* meadow, as was found in the chronic disturbance experiment, one year of camping did not have a significant impact on vegetation cover, either on sites camped on one night ($P = 0.25$) or on sites used four nights ($P = 0.97$) (Figure 5). Consequently, it was not possible to assess recovery of vegetation cover in the meadow.

In contrast, just one year of camping reduced vegetation cover substantially on the central portion of sites in forest with *Vaccinium scoparium* understory. Sufficient recovery occurred over the subsequent three years without camping disturbance for relative vegetation cover to vary significantly with years of recovery ($F = 4.2$, $P = 0.03$). Relative vegetation cover after the second year of recovery was significantly higher than cover after the first year of recovery ($F = 4.0$, $P = 0.05$); cover after the third year of recovery was higher still, although this contrast did not meet the 0.05 standard for significance ($F = 3.5$, $P = 0.06$). Despite substantial recovery, after three years without further disturbance, both the sites camped on once and the sites camped on four times had significantly less vegetation cover than controls ($P = 0.04$ and < 0.01, respectively). Extrapolating a linear recovery rate, it would take about five years for sites camped on for one night to regain the vegetation cover

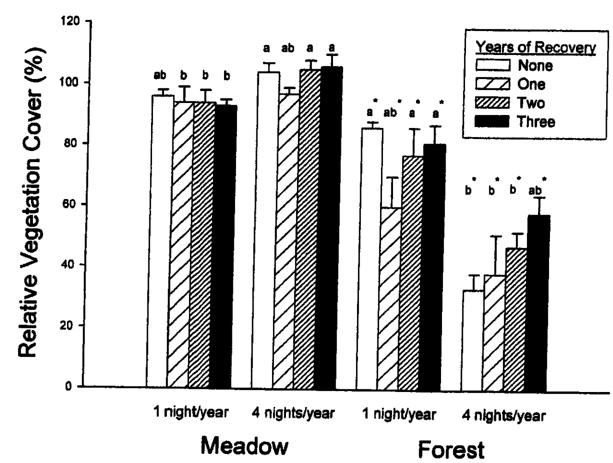

Figure 5. Relative vegetation cover (mean + 1 SE), near the center of meadow and forest sites immediately after one and four nights of camping, as well as after one, two, and three years of recovery. Within each plant community, treatments with the same letter are not significantly different ($\hat{\alpha} = 0.05$). *Treatments differ from controls.

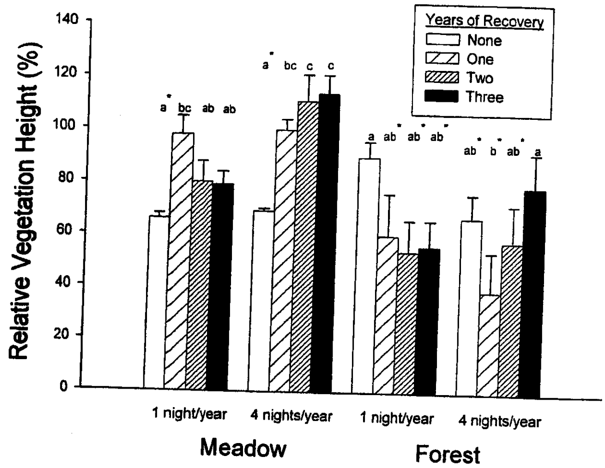

Figure 6. Relative vegetation height (mean + 1 SE), near the center of meadow and forest sites immediately after one and four nights of camping, as well as after one, two, and three years of recovery. Within each plant community, treatments with the same letter are not significantly different ($\alpha = 0.05$). *Treatments differ from controls.

they originally had (i.e., reach relative vegetation cover of 100%). It would take about eight years for sites camped on for four nights to completely recover their vegetation cover.

In the meadow, as was found in the chronic disturbance experiment, vegetation height declined significantly after a single season of camping at intensities of one and four nights per year (Figure 6). At both use intensities, however, vegetation height returned to pretreatment levels after just a single year of recovery. In this plant community, relative vegetation height did not vary significantly with years of recovery ($F = 0.1$, $P = 0.93$) or nights of camping ($F = 2.8$, $P = 0.12$). This corroborates the results from the other experiment, in which complete recovery occurred between years of camping. Besides being highly resistant to vegetation impact, this plant community appears to be highly resilient, at least to low levels of disturbance.

In the forest, recovery of plant stature was much less pronounced than in the meadow (Figure 6). Recovery of plant stature was also less pronounced than recovery of vegetation cover. For relative vegetation height in the forest, there was a significant interaction between years of recovery and nights of camping ($F = 5.9$, $P < 0.01$). On sites used once, vegetation height did not recover significantly over three years without camping ($F = 0.4$, $P = 0.71$). On sites used four nights, vegetation height increased significantly with successive years of recovery. Differences between the second and third years without camping were significant ($F = 45.5$, $P < 0.01$), while differences between the first and second year failed to meet the 0.05 standard of significance ($F = 4.1$, $P = 0.07$). It is not clear why recovery was greater on the more frequently used sites. What is clear is that—as was the case with vegetation cover—recovery of vegetation height after a single night of camping in this plant community will require more than a few years.

Effects at the Scale of the Entire Campsite

Estimates of the magnitude of impact should vary with the spatial scale of analysis. So should temporal patterns of impact and the nature of the relationship between impacts and explanatory variables such as frequency of use and plant community. Scaling up from the central portion of the campsite to the entire 49 m^2 campsite, we hypothesized that the impacts resulting from a given amount of use would decline and that the time required for impact to occur or to reach near-maximum levels would increase. These hypotheses reflect the expectation that camping activities are concentrated close to the center of the campsite and that higher levels of activity will increase both the magnitude of impact and the rate at which impact occurs. Although we expected spatial scale to have no influence on the relative durability of these two plant communities, we could not predict the effect of spatial scale on the magnitude of difference between the two communities. Nor could we predict the influence of different scales of analysis on conclusions regarding resilience.

As expected, magnitude of impact decreased at larger spatial scales. The mean relative vegetation cover after one, two, and three successive years of camping, was generally higher when the entire 49 m^2 of campsite was assessed (Figure 7) than it was in the central portion of the site (Figure 1). The magnitude of difference in impact between the resistant meadow and the nonresistant forest was less pronounced at the scale of the entire campsite than it was close to the center of the campsite. Sites in the *Deschampsia cespitosa* meadow were not highly impacted regardless of the scale of analysis. Although impacts were widespread on sites in the forest with *Vaccinium scoparium* understory, they were much more pronounced at the center of the site. Mean relative cover after three successive years of four nights per year of camping was 6% in the center compared to 36% on the 49-m^2 campsite.

The rate at which impact occurred when subjected to chronic disturbance also decreased at higher spatial scales. In the *Deschampsia cespitosa* meadow, at the scale of the entire campsite, four nights of camping per year did not cause a significant loss of cover until the third

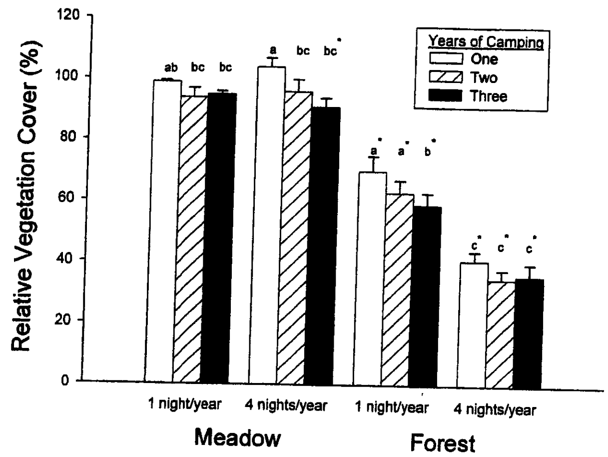

Figure 7. Relative vegetation cover (mean + 1 SE) of 49 m^2 meadow and forest sites after one, two, and three years of camping at intensities of one and four nights per year. Within each plant community, treatments with the same letter are not significantly different (α = 0.05). *Treatments differ from controls.

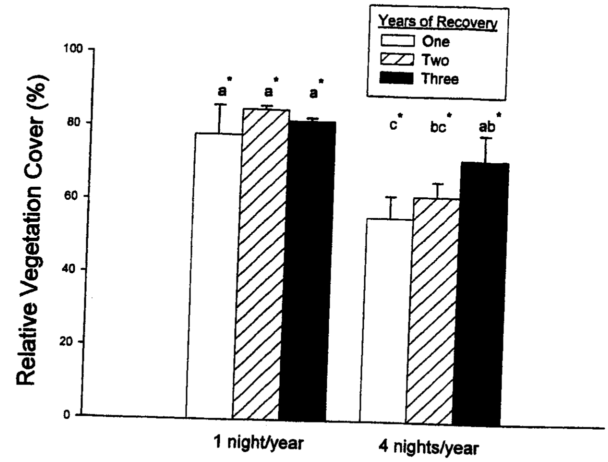

Figure 8. Relative vegetation cover (mean + 1 SE) of 49 m^2 forest sites one, two, and three years after one and four nights of camping. Treatments with the same letter are not significantly different (α = 0.05). *Treatments differ from controls.

successive year of camping (P = 0.01). Close to the center of the site, two years of camping at this intensity caused significant impact. At the scale of the entire campsite, sites in the forest with *Vaccinium scoparium* understory experienced a significant further decline in relative vegetation cover after the second successive year of camping (F = 8.7, P = 0.02). In the central portion of the site, near-maximum levels of impact occurred after a single year of camping, so cover after subsequent years was not significantly different.

The effect of scale of analysis on resilience could only be assessed in the forest where, even at the scale of the entire campsite, sites camped on for just one night did not recover completely in three years (Figure 8). Recovery of these lightly used sites was much less pronounced when analyzed at the scale of the entire site than when only the central portion of the site was assessed (Figure 4). Recovery of the sites camped on four nights per year was similar regardless of the scale of analysis. Seasonal recovery between successive years of camping (data not shown) was also generally equivalent at the two scales of analysis. It appears that recovery rates decline as relative vegetation cover approaches 80%.

Discussion and Conclusions

These experiments clearly illustrate that low levels of camping can cause substantial vegetation loss. Moreover, the campers that caused these impacts were modest-sized groups of four who were trained in the techniques of minimum-impact camping and who did not have campfires. Although the goal of camper education programs is to make Leave No Trace camping the norm, these estimates of the magnitude of camping impacts should be considered conservative. Most groups, camping at the frequencies employed in these experiments, would cause higher levels of impact. Further research is needed to quantify the impacts resulting from use by more typical camping groups.

Differences in impact between the two plant communities were profound, however. The magnitude of vegetation loss on meadow sites, after four nights per year of camping for three successive years, was less than half that caused by a single night of camping on the forested sites. In the meadow, only the sites camped on for at least two years at a use frequency of four nights per year were significantly impacted. Differences in the magnitude of effects on vegetation height were also substantial, although less pronounced (Figure 2). Meadow sites were also more resilient than the forest sites. The fragility of the forest with *Vaccinium scoparium* understory is a particular concern because this is the most common and widespread vegetation type in the subalpine zone throughout the Rocky Mountains and is probably the vegetation type most frequently used for camping.

These results are consistent with those of trampling experiments conducted in these same plant communities, where similar trampling intensities caused an order of magnitude more cover loss in the forest than in the meadow (Cole and Monz 2002). Previous trampling studies have shown that graminoids and low-growing forbs (abundant in the *Deschampsia cespitosa* meadow) are generally resistant and resilient, while low-growing shrubs (dominant in the forest with *Vaccinium scoparium* understory) are not very resistant and have very little resilience (Cole 1995b). The two plant communities included in this study probably define much of the range of variation in response to camping. Few vegetation types are much less durable than the forest with *Vaccinium scoparium* understory; however, many plant communities are even more resistant and resilient than the *Deschampsia cespitosa* meadow (Cole 1995b, Cole and Monz 2002).

The most unique aspect of our study—beyond the use of realistic camping treatments—was our ability to assess temporal patterns of response. On the forest sites, regardless of camping frequency, near-maximum levels of impact were caused by the first year of camping; subsequent years of camping had no additional effect (Figures 1 and 2). For this plant community and disturbance intensity, the effects of acute and chronic disturbance are equivalent. In the more resistant meadow community, chronic disturbance caused more impact than acute disturbance (Figures 1 and 2). Vegetation impact occurred only at camping frequencies of four nights per year and only after two successive years of camping. On these sites as well, the third year of camping did not cause substantially more impact than the second year.

In trampling experiments, Cole and Monz (2002) found that resilience declined with chronic disturbance. In these camping experiments, however, there was little evidence of declining resilience, with successive years of camping (Figures 3 and 4). This may merely reflect the fact that substantial impact never occurred on meadow sites and that near-maximum levels of impact occurred on even the lightly used forested sites. Perhaps of most interest regarding recovery rates was our finding that, particularly on forested sites, recovery rates tended to decline with successive years since disturbance (Figures 5 and 6). This suggests that complete recovery from a single night of camping on forest sites, for example, is likely to require more than the five years estimated by a linear extrapolation of initial recovery rates.

These results also conform to the oft-reported generalization (e.g., Leung and Marion 2000) that most impact occurs at low levels of use and further increases in impact are not proportional to further increases in use. In the forest, sites camped on one night per year lost more than half their vegetation cover and height (Figures 1 and 2). Consequently, it was impossible for sites used four times as frequently to experience four times as much vegetation impact. On meadow sites, neither vegetation cover nor vegetation height varied significantly with use frequency. However, the mean reduction (100% minus relative vegetation cover or height) on sites used four nights per year was generally about twice that on sites used one night per year (Figures 1 and 2). In the meadow, recovery occurred more rapidly on sites used four nights than on sites used once. In the forest, extrapolation of recovery rates suggests that sites used four nights will take no more than twice as long to recover as sites used once.

These experiments also illustrate the effect of scale of analysis on both estimates of the magnitude of impact and generalizations about spatial and temporal patterns of impact. Estimates of the magnitude of impact declined as the scale of analysis increased. Since camping activities are concentrated close to the center of the site, vegetation loss is more pronounced there and the impact of a given frequency of use declines as the scale of analysis is expanded to include more peripheral portions of the campsite. At the scale of the stand within which these campsites are located, only a few percent of the understory vegetation cover was affected by camping and at the scale of the entire park or wilderness area, these impacts are negligible. This suggests that, for comparative purposes, a measure of the extent of impact is a more appropriate impact parameter than intensity metrics such as percent vegetation cover. For example, area of vegetation loss (Cole 1989), mean percent vegetation loss multiplied by the area of disturbance, has been used as a basis for comparing impacts across areas with widespread variations in spatial extent (Marion and Farrell 2002).

Estimates of the difference in durability of the two plant communities decreased as the scale of analysis expanded from the campsite center to the entire 49-m^2 campsite. At larger spatial scales, differences between plant communities in the impact caused by a given amount of use are likely to become negligible. This relationship between scale and magnitude of difference should vary with the difference in durability of the two communities and with the intensity of disturbance. As the difference in durability decreases, the effect of scale on magnitude of difference should also decline. Differences at larger spatial scales should be more pronounced as disturbance intensity increases.

The rate at which impact occurred also decreased as spatial scale increased. Studies that show the slow and steady proliferation of campsites in parks and wilderness areas (e.g., Cole 1993) suggest that the rate at which impact occurs is likely to decrease and the time period over which impact increases is likely to lengthen as the scale of analysis is enlarged to include the stand, the watershed and the entire wilderness.

The practical implications of these results to managers working to avoid recreation impacts are both encouraging and discouraging. The profound difference in durability between the two plant communities suggests that impact levels can be limited by controlling where people camp. Appropriate campsite selection is clearly among the most critical of the Leave No Trace skills (Hampton and Cole 1995). Unfortunately, it also appears to be among the most difficult skills to learn (Cole and others 1997), a problem that is aggravated by the frequency with which managers recommend not camping in meadows, on the erroneous belief that meadows are more fragile.

The magnitude of impact that results from infrequent camping by groups well-versed in Leave No Trace clearly illustrates that, while helpful, minimum impact education by itself cannot guard against substantial impact. Impact is inevitable wherever regular recreation use occurs. The low-use frequencies that cause substantial impact and the lengthy recovery periods required illustrate the importance of managing camping impacts before they intensify and proliferate unacceptably. They validate the effectiveness of management strategies that confine the impacts of use (Marion and Farrell 2002) and the potential adverse consequences of promoting dispersal of camping activities.

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