Vegetation and Soil Restoration on Highly Impacted Campsites in the Eagle Cap Wilderness, Oregon

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Abstract

We assessed the effectiveness of planting techniques (seeding and transplanting) and restoration treatments designed to improve the physical, biological, and chemical properties of soils and ameliorate microclimatic conditions on six closed campsites in subalpine forests. Restoration treatments included scarification, soil amendment with organic matter, compost and soil inoculum, and application of a mulch blanket. Campsite closure, scarification, planting, and soil amendments were successful in increasing recovery rates. The mulch blanket had no effect on recovery. 10 years after campsite closure, vegetation cover was still diminished in comparison to reference conditions on nearby undisturbed sites. Particularly problematic was reestablishment of the low-growing shrub species (particularly *Vaccinium scoparium* and *Phyllodoce empetriformis*) that are the most abundant groundcover species in these forests. These species seldom establish from seed. Moreover, survivorship and growth rates are unusually low for transplants. Our results show the relative ease of establishing various species and growth forms in these forests, as well as which species and growth forms respond best to the applied treatments. Results reinforce the importance of avoiding impacts in the first place, the lengthy recovery periods required in these ecosystems, and the intensive restoration efforts needed to speed recovery.

Key words: compost, mulch, recreation impact, scarification, seeding, soil amendments, transplanting

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cover photos: (top) Closed campsite at Horseshoe Lake 10 years after restoration treatments were applied. ***(middle)*** Groundcover vegetation on a sample plot, 10 years after scarification, planting and soil amendments. ***(bottom)*** Amending the soil of a long-disturbed campsite with organic matter, compost and native soil inoculum.

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Contents

Introduction

Subalpine lakes are magnets for recreation use throughout the mountainous wilderness of the western United States. People flock to these lakes for their outstanding scenic qualities, as well as to fish, swim, picnic, and camp. Although use is much greater today than it was before the 1960s, some popular lakes have been regularly visited for the better part of a century. Regularly visited places, particularly those that serve as campsites, quickly become impacted. Understory vegetation disappears, as do organic soil horizons. Exposed mineral soil becomes highly compacted, reducing rainfall infiltration and increasing erosion.

Wilderness managers are concerned about such campsite impacts given their mandate to preserve natural conditions in wilderness. While it is clear that some level of impact is inevitable if overnight camping is allowed, these impacts may be more numerous than they should be or may be occurring in locations where they are considered unacceptable. Increasingly, managers are closing impacted sites to camping to allow them to return to pre-disturbance conditions. This goal has often proved elusive, however. Recovery cannot occur unless all site use is curtailed. Wilderness managers are often reluctant to erect the signs and ropes that can be effective in keeping walkers, anglers, and picnickers, as well as campers, off closed campsites.

Even where recreational use is effectively curtailed, recovery can be an extremely slow process in subalpine ecosystems. Growing seasons are short and climatic conditions during these seasons can be harsh. Many of the abundant subalpine plants establish infrequently and grow slowly. Moreover, the soil on many closed sites no longer provides a good growing medium for plants. Many decades without vegetation and with minimal organic input have left the plants physically, biologically, and chemically impoverished. Managers often responded by employing various restoration techniques in attempts to accelerate successional processes (Lester 1990). However, these efforts are often costly in terms of time and money, and frequently are not very successful (Moritsch and Muir 1993).

Given the lack of information on effective means of restoring subalpine campsites, we initiated long-term experiments using several common restoration treatments. Specifically, we assessed the effectiveness of (1) scarification, (2) transplanting and seeding with local, native species, (3) ameliorating microclimatic conditions with a mulch mat, and (4) amending soils with organic matter, compost, and soil inoculum. Treatment effects were closely followed for 10 years.

Study Sites

The study was conducted on six campsites in the Eagle Cap Wilderness, Wallowa Mountains, northeastern Oregon. All sites were located at an elevation of 2215 to 2300 m, adjacent to subalpine lakes, about 12 to 15 km from the closest road. They were located in forests with an overstory of *Abies lasiocarpa* (subalpine fir), *Pinus contorta* (lodgepole pine), and *Pinus albicaulis* (whitebark pine). Ground cover vegetation on adjacent, little disturbed sites is discontinuous (typically about 50 percent cover). Ericaceous dwarf shrubs, *Vaccinium scoparium* (grouse whortleberry) and *Phyllodoce empetriformis* (red mountain heather), and the caespitose graminoids, *Juncus parryi* (Parry's rush) and *Carex rossii* (Ross' sedge), are the most abundant species.

This plant community type occurs throughout much of the western United States at high elevations, particularly in locations that are popular destinations for wilderness recreation. The impacts of wilderness camping are probably more common in this community type than any other in the United States, making information about effective restoration techniques particularly useful in this type. Soils are shallow, sandy, and acidic (pH between 4.2 and 4.8) and are derived from granitic substrates (Cryochrepts and Cryorthents). Although snow typically covers the ground until late June/early July, snowmelt is typically followed by hot, dry summers. The frequency of summer thunderstorms varies from year to year. When they are infrequent, soils can be highly droughty for several months (most of the growing season).

These campsites have probably exhibited high levels of impact (lack of vegetation, minimal soil organic horizons, and compacted mineral soil) for at least 50 years. Prior to restoration, these campsites were typically about 200 m^2 in size, with about 100 m^2 completely devoid of vegetation. Soil organic horizons had eroded away over substantial portions of these sites and mineral soils were so compacted that infiltration rates were reduced by almost 50 percent (Cole and Fichtler 1983). Potentially mineralizable N and microbial activity were also substantially reduced on these campsites (Zabinski and others 2002).

Methods

Treatments

Campsite restoration began in 1995 with the closure of these sites to camping, using closure signs and rope. The closures were highly effective. Over the 10 years of the study, we found only a few instances where it appeared someone had walked on the plots. Nobody camped on any of the sites.

A three-factor experiment, using a split plot design was employed. Twelve treatment plots (1.5 m by 1.5 m) were established on each campsite. The soil was scarified on these plots. Scarification involved the use of shovels, picks, pitchforks, hoes, and hand kneading to break up compaction and clods to a depth of about 15 cm. Substantial mixing of soil horizons was unavoidable in our resolve to develop a crumb texture. On several sites, numerous tree roots were cut and removed during scarification. This intensity of scarification exceeds that commonly undertaken on wilderness campsites.

A control plot (not treated in any way) was established within the closed area on a part of the campsite that was not scarified. This plot was used in an analysis, separate from the factorial experiment, of the effect of scarification in the absence of mulch, soil amendments, and planting.

Of the three factors in the split plot experiment, the mulch treatment was the factor used to establish whole plot units because it was most feasible to apply mulch blankets over large areas. Six contiguous plots on each site were covered with a biodegradable mulch made of straw interwoven with cotton string and jute (Bionet®)(fig. 1). The other six contiguous plots were not mulched. Within each of the two mulch whole plots, three levels of soil amendment and two levels of planting were assigned to split-plot units in a completely randomized design. Each combination of soil amendment and planting occurred in each whole plot. Figure 2 illustrates the layout for one of the campsites. Each campsite had a unique ordering of treatments within the mulch whole plots. Each campsite provided one of six replicates.

Figure 1. The appearance of the mulch blanket immediately after planting.

There were three levels of the soil amendment factor. Within each whole plot, two treatment plots (split-plot units) received no amendments. Another two plots were amended with organic matter and inoculated with native soil. The organic matter was a mix of peat moss (20 percent) and well decomposed, locally collected organic matter. The dry peat moss was mixed with water before application. A 2.5 cm layer of this organic material was mixed with mineral soil to a depth of 7.5 cm (fig. 3). Soil from the rooting zone of local transplants was the source for the inoculum. About 1.2 liters of soil were mixed with about 20 liters of water to make a slurry. Three liters of this slurry were sprinkled over each plot and raked into the soil. The final two plots were amended with compost in addition to the organic matter and inoculum treatment. We added 2.5 cm of commercially available compost (sewage sludge/log yard waste compost with a C:N of approximately 20:1; Ekocompost®, Missoula, Montana), lightly watered and raked into the top 10 cm of organic and mineral soil.

Mulch No Seed O&C Soil A Scarified	Mulch Seed No Soil A Scarified	Mulch No Seed O Soil A Scarified	Mulch No Seed No Soil A Scarified	Mulch Seed O Soil A Scarified	Mulch Seed O&C Soil A Scarified	No Mulch No Seed No Soil A No Scarif
No Mulch Seed No Soil A Scarified	No Mulch Seed O&C Soil A Scarified	No Mulch Seed O Soil A Scarified	No Mulch No Seed No Soil A Scarified	No Mulch No Seed O Soil A Scarified	No Mulch No Seed O&C Soil A Scarified	

Figure 2. Distribution of treatments for one campsite, illustrating completely random assignment of treatments within mulch whole-plot units, as well as the separate non-scarified control. Treatments are: mulch or no mulch; seed or no seed; no soil amendment, organics amendment or organics and compost amendment; and scarified or not scarified.

Figure 3. Application of soil amendments.

Figure 4. Planting a transplant.

Figure 5. Typical transplant cover and density immediately after planting.

The two levels of planting were planted and unplanted. Within each whole plot, three plots were planted (seeded and transplanted) and three were not. Seeding involved (1) collecting seed locally from several species with mature seed, (2) dividing available seed into equal quantities for each seeded plot, (3) pinch-broadcasting seed over the plot, and (4) raking seed into the upper 2.5 cm of soil. Seeded species varied between campsites depending on locally available plants with mature seed. *Juncus parryi* and *Phleum alpinum* (alpine timothy) were seeded on three of the campsites. *Antennaria alpina* (alpine pussytoes), *Antennaria lanata* (woolly pussytoes), and *Sibbaldia procumbens* (creeping sibbaldia) were seeded on two campsites. *Aster alpigenus* (alpine aster), *Danthonia intermedia* (timber oatgrass), *Penstemon globosus* (globe penstemon), and *Sitanion hystrix* (bottlebrush squirreltail) were each seeded on one campsite. Locally available seed was unusually limited due to the unusually short growing season in 1995. One of the campsites (at Crescent Lake) was not seeded due to a lack of mature seed in the vicinity.

Transplanting involved (1) digging up enough transplants in the vicinity to plant equal numbers of each species in each plot, (2) digging a hole and placing transplants in the hole, along with Vita-start (vitamin B-1) to reduce transplant shock (fig. 4), and (3) giving each transplant 0.6 liters of water. Plots not planted were given an equivalent amount of water. Most transplant plugs were between 5 and 25 cm in diameter, and most plots received five to six plugs (fig. 5). Most plugs contained only one species, but some contained more than one. Transplanted species varied between campsites. *Vaccinium scoparium* and *Juncus parryi* were intentionally transplanted on five of the six campsites. *Phyllodoce empetriformis, Carex rossii*, *Luzula hitchcockii* (smooth woodrush), and *Sibbaldia procumbens* were intentionally transplanted on two campsites. Species that were intentionally transplanted on only one campsite were *Abies lasiocarpa, Achillea millefolium* (yarrow), *Antennaria alpina*, *Antennaria lanata*, *Aster alpigenus*, *Calamagrosts canadensis* (bluejoint reedgrass), *Danthonia intermedia, Hypericum formosum* (western St. John's-wort), *Oryzopsis exigua* (little ricegrass), *Pinus contorta, Polemonium pulcherrimum* (showy polemonium), and *Spiraea betulifolia* (shiny-leaf spirea). Thirteen other species were unintentionally included in plugs. Nomenclature follows Hitchcock and Cronquist (1973).

Seeding and transplanting occurred only in the central 1 m^2 of each plot. Measurements were also confined to this central area, leaving a 0.5 m buffer between the measured portion of each treated plot. In 1996, when it appeared that soils were extremely dry, plots were watered several times. We did this because reports from earlier campsite restoration projects in the Pacific Northwest indicated that it is common for most seedlings to die during prolonged periods of summer drought

(Lester 1990). All plots were given an equal amount of water (about 2 liters per plot). No supplemental watering occurred in later years.

Climatic variability clearly influenced temporal patterns of plant response, primarily by determining the availability of soil moisture. Although there was yearly variation, growing season conditions generally became increasingly droughty over the 10-year study period. For the first 4 years of the study, the late snowpack was unusually deep, suggesting that early season conditions were much less droughty than normal. This was not the case for the final 6 years of the study. In 1996, the first growing season after restoration, when plots were occasionally irrigated, the summer was dry but cool. In 1997, the summer was cool and wet. In 1998, the summer was hot and dry, and plants were not given supplemental water. Long-term, regional drought set in with the hot, dry summer of 2000 and the generally low precipitation that fell throughout 2001. Drought persisted through 2005.

Measurements

We measured transplant survival and growth, seedling density and plant cover at least once every year for 7 years (fig. 6). In addition, cover was assessed after 10 years.

Transplants—For each transplant, we measured areal extent of canopy cover (using a 1 m square PVC frame with a 5 cm by 5 cm grid) and maximum height. Measurements were taken immediately after transplanting (September 1995) and in each September thereafter, for 7 years (through 2002).

Seedlings—Seedling establishment was assessed beginning in early July 1996. Every two weeks from early July to early September (four times), all established seedlings were mapped. Each seedling was identified by species, and a colored toothpick was placed next to it to denote date of establishment. This made it possible to assess period of establishment and death if mortality occurred. In 1997, seedlings that germinated in 1996 were identified on the basis of their size, location, and species. New seedlings (the 1997 cohort) were identified in the surveys conducted every two weeks. In some plots, seedlings were so numerous that they were assessed in subplots. In 1998, seedling assessment occurred twice, in mid-July and early September. In subsequent years (through 2002), we assessed the density of seedlings (plants that had established by seed since the beginning of the study) only in September.

Figure 6. Quadrats used to assess plant cover, seedling density, and transplant growth.

Each year, 10 individuals of a seeded species were randomly selected on each plot, and their height was measured in September. In 1996 and 1997, we excavated four individuals of the same species that were growing within the treated plot, but outside the area where measurements were taken. Their root and shoot biomass was measured following cleaning and drying. In 1998, we measured the height of the tallest individual of the seeded species, which we found to be highly correlated with biomass. This avoided the need for further destructive sampling. In 1997 and 1998, height and biomass measurements were taken only on seedlings that germinated and established in 1996. In 1996 and 1997, transplant areal extent and seedling locations were digitized to allow spatial analysis.

Plant cover—Every September between 1996 and 2002, total plant cover was ocularly estimated to the closest percent if cover was 10 percent or less and in 10 percent increments thereafter. Total vegetation cover was assessed, as was the cover of each transplanted species and each species that had established from seed. Final cover estimates were taken in September 2005, 10 years after seeding and transplanting.

Reference conditions—Total vegetation cover and the cover of individual species were estimated in undisturbed plots near to each restored campsite. The means from these six plots are used as targets for successful restoration.

Soil characteristics—Soils analyses were conducted twice during the study. Three years after the restoration treatments, soil samples were collected on each campsite from (1) plots that received the treatment of organics, inoculum, and compost, (2) untreated parts of the closed campsite, and (3) undisturbed sites adjacent to the campsites. Parameters assessed were: microbial biomass C, basal respiration rates, total organic carbon, total nitrogen, ammonium, potentially mineralizable nitrogen, and several indicators of the carbon utilization capabilities of the microbial community. Details of the laboratory analyses and results can be found in Zabinski and others (2002). In 2003, 8 years after the restoration treatments, soil samples were again taken on each campsite. As before, samples were taken from untreated parts of the closed campsite and from undisturbed sites adjacent to the campsites. This time, however, the effects of six different treatments were assessed: planted plots that received each of the three soil amendment treatments and unplanted plots that received each of the three soil amendment treatments. In each case, only plots that were not covered with the mulch mat were sampled. Soil analysis procedures were identical to those used 5 years earlier, except that carbon utilization capabilities were not investigated.

Data Analysis and Presentation

Some of the results of this study are presented in more detail elsewhere. Zabinski and others (2002) describe results of the early soils study. Cole and Spildie (2006) and Cole (in press) present detailed results for transplants and seedlings, respectively. In this report, results presented elsewhere are only briefly reviewed. Most attention is given to the effect of restoration on soil 8 years after treatment and to how plant cover responded to treatment over the 10-year study period.

The soils data are analyzed using paired t-tests and univariate analyses of variance in SPSS 9.0. First we tested differences between untreated parts of the campsite and undisturbed control sites using paired t-tests. Then we tested the effects of the main factors, soil amendment, and planting on soil characteristics. Most data were square-root transformed to better comply with assumptions about normality. Where there were significant main effects, we assessed the significance of differences between means using Tukey's honestly significant differences test, which adjusts for multiple comparisons. Then we assessed which treatments differed from the untreated campsite using Dunnett's tests. Finally, we assessed which treatments differed from undisturbed controls, also using Dunnett's tests.

For the cover data, we performed repeated measures analyses of variance, appropriate for split-plot designs (using an autoregressive covariance structure, PROC MIXED in SAS 9.1). Most data were square-root transformed to better comply with assumptions about normality. In many cases, treatment effects varied significantly with time since treatment (in other words, interactions with time were significant). In these cases, we describe treatment effects for each of the 10 years of the experiment, but the significance of effects is only assessed at the end of the experiment, in 2005. In those cases where treatment interactions with time were not significant, we report results of the repeated measures analyses.

To assess the hypothesis that scarification has positive effects, the control (the plot that was not even scarified) was compared to the one plot on each campsite that was scarified but not mulched, amended, or planted. For the three factors included in the split plot design (mulch, soil amendment, and planting), main effects of each factor and interactions among factors were assessed. Interactions among the treatments were never statistically significant. Therefore, we simply report the main effects of treatments. We report ANOVA treatment effects when there are two treatments being compared (effects of scarification, planting, and mulch). For the soil amendments, we report Dunnett's tests, adjusted for multiple comparisons, of differences between each of the two amendments and the non-amended treatment, as well as Tukey-Kramer tests, adjusted for multiple comparisons, of differences between the two amendments.

Results

Effects on Soils

Compared to undisturbed controls, unrestored campsite soils had significantly lower organic carbon (C), total nitrogen (N), ammonium (NH4), potentially mineralizable nitrogen (PMN), and microbial biomass (fig. 7). Basal respiration rates (an indicator of the magnitude of microbial populations) did not differ significantly. These results, based on soils collected in 2003, 8 years after the beginning of the experiment, are similar to those reported for soils collected in 1998 (Zabinski and others 2002). In 1998, basal respiration rates did differ between campsites and controls if the soil on controls was collected immediately underneath vegetation, rather than in open areas between vegetation clumps. Zabinski and others (2002) also report that control sites had higher measures for an indicator of the functional diversity of microbial populations, the number of substrates metabolized in carbon utilization profiles.

Since camping reduced levels of most of these parameters, we hypothesized that soil amendments and planting might accelerate soil recovery and increase levels of these parameters. The soil amendments had much more pronounced effects on soil characteristics than whether or not plots were transplanted and seeded

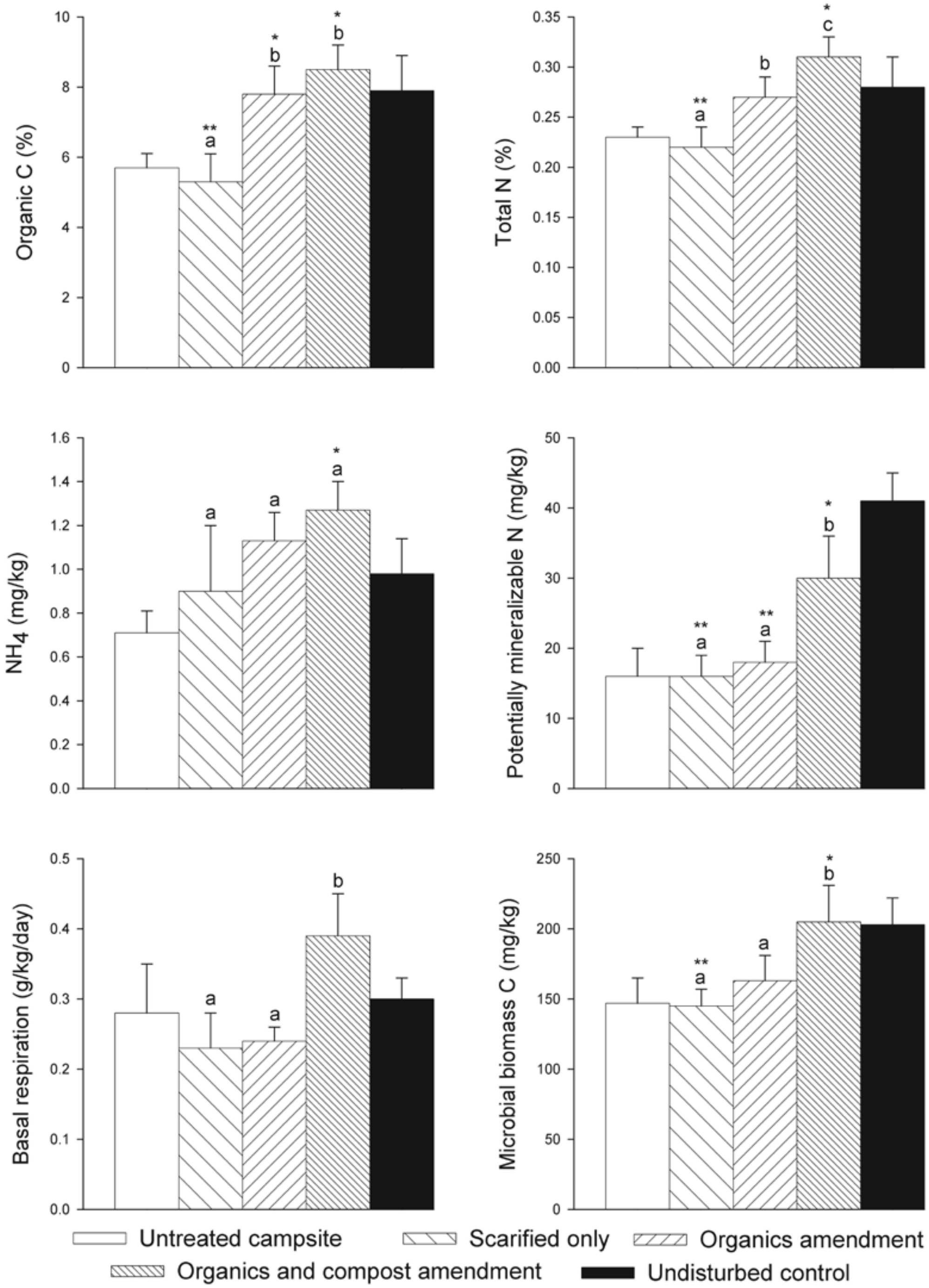

Figure 7. Effect of restoration treatments on soil characteristics.

(table 1). Compared to soil in plots that were only scarified, the soil in plots amended with organics and compost had significantly higher levels of organic C, total N, potentially mineralizable N, basal respiration rates, and microbial biomass (fig. 7). In the plots amended with organics only (no compost), soils had significantly higher levels of organic C and total N than on scarified plots and significantly lower levels of organic N, potentially mineralizable N, basal respiration rates, and microbial biomass than on organics and compost plots.

Plots amended with organic matter and compost differed significantly from untreated campsites for all parameters other than basal respiration. Moreover, plots amended with organics and compost were not significantly different from controls for any of these parameters. This suggests amendment with organics and compost

Table 1. Analysis of variance results (F values) for the effect of soil amendments and planting on soil characteristics.

Source of variation	df	Organic C	Total N	NH_4	PMN	Respiration	Biomass C
				F			
Soil amendment	2	14.7**	18.5**	0.2	5.5*	5.1*	3.6*
Planting	1	5.9*	7.1*	1.4	1.2	0.8	1.2
Interaction	2	1.8	2.0	0.2	2.3	0.3	1.5

Significance: *<0.05; **<0.01

was sufficient to ameliorate many of the effects of long-term camping on these soils, without exceeding levels found in undisturbed soils. Plots amended with organics only had soil characteristics that were consistently intermediate between those for untreated campsites and control sites. However, organics only plots differed significantly from untreated campsites only in organic C. They differed from controls only in potentially mineralizable N. Plots that were only scarified did not differ significantly from untreated campsites for any of these parameters. They differed from controls for all parameters other than NH_4 and basal respiration.

For most of these parameters, the soil in plots that were transplanted and seeded was not significantly different from the soil in plots that were not planted. Contrary to our hypotheses, organic C was significantly lower on planted plots (6.5 percent) than it was on plots that were not planted (8 percent). Similarly, total N was significantly lower on planted plots (0.25 percent) than it was on plots that were not planted (0.28 percent). Neither of these differences seems substantial, but clearly planting alone does not lead to rapid recovery of soil properties.

Effects on Total Plant Cover

Following closure and restoration of the campsites, total plant cover increased from zero to 12 percent 10 years later (table 2). Total cover reached a maximum of almost 15 percent in 1999 and declined somewhat thereafter. This response pattern was particularly pronounced on plots that were amended with organics and compost, suggesting that the effect of amendments was most dramatic in the first few years following treatment. The pattern was also more pronounced on planted plots, particularly for seeded species.

Total vegetation cover is still substantially below the 50 percent cover that is typical of adjacent undisturbed vegetation. Initially, transplants accounted for most of the cover. After 10 years, however, the total cover of plants that germinated from seed—both intentionally seeded and volunteer (11 percent)—approximated that of transplants (12 percent) on plots that were planted. Similarly, seeded plants were initially much more abundant than plants that volunteered (plants that germinated from seed in the soil seedbank or that dispersed naturally onto the site). After 10 years, cover of volunteers was only slightly lower (5 percent) than cover of seeded plants (6 percent) on seeded plots. On plots that were not seeded and transplanted, volunteers accounted for all the vegetation cover. Non-native species were absent.

Treatment effects—Restoration treatments varied in effectiveness (fig. 8). Mere closure was not successful. On plots that were not scarified, mean cover never exceeded 1 percent and was only 0.4 percent 10 years after closure. Scarification alone was slightly more successful (fig. 9). Plant cover was significantly greater on plots that were scarified (but not seeded, amended with organics, or mulched) than on control plots that were closed

Table 2. Variation in plant cover (percent) over the 10-year study.

	1996	1997	1998	1999	2000	2001	2002	2005
All plants (total cover)	8.0	7.2	13.3	14.7	12.1	9.7	9.4	12.4
Transplants[a]	11.3	9.1	13.3	13.2	10.4	9.2	9.4	12.1
Seeded plants[a]	5.6	5.2	9.9	10.8	9.5	6.0	4.7	6.3
Volunteer seedlings[b]	1.6	2.4	4.9	6.5	5.3	3.9	4.0	4.7

[a] For transplants and seeded plants, cover is the mean of those plots that were planted.
[b] Volunteer seedlings cover is derived from all plant cover on unplanted plots, and from the cover of seedlings of species that were not seeded on planted plots.

Figure 8. Variation in effectiveness of treatments 2 years after treatment.

Figure 9. Effect of scarification (but no other treatments) on plant cover.

Table 3. Effect of scarification on plant cover, repeated measures analysis of variance results.

Effect	df	F	p
Scarification (S)	1	3.84	0.03*[a]
Year (Y)	7	0.50	0.83
Interaction (S*Y)	7	1.21	0.30

* Denotes a statistically significant difference (α = 0.05).
[a] One-tailed test of hypothesis that cover would increase with scarification.

to use but received no restoration treatments (table 3). However, differences were small. 10 years after closure, mean plant cover on scarified-only plots was less than 3 percent.

The planting (both transplanting and seeding) treatment had the most pronounced effect on plant cover (table 4). Magnitude of effect varied significantly with year since planting (that is, the interaction between planting and year was significant). Consequently, the significance of treatment effects was assessed at the end of the study, in 2005 (table 5). 10 years after planting, cover was more than three times greater on planted plots

Table 4. Effects of planting, soil amendments, and mulching on plant cover, repeated measures analysis of variance results.[a]

Effect	df	F	p
Planting (P)	1	186.4	<0.01*
Soil amendment (S)	2	6.6	<0.01*
Mulch (M)	1	0.1	0.83
P*S	2	2.4	0.12
P*M	1	0.2	0.69
S*M	2	0.6	0.56
Year (Y)	7	17.7	<0.01*
Y*P	7	5.4	<0.01*
Y*S	14	2.3	<0.01*
Y*M	7	1.8	0.10

* Denotes a statistically significant difference (α = 0.05).
[a] Higher order interactions were not significant and are not shown.

Table 5. Effects of planting, soil amendments, and mulching on plant cover in 2005.

Effect	df	F	p
Planting (P)	1	79.5	<0.01*[a]
Soil amendment (S)	2	5.6	0.01*[a]
Mulch (M)	1	3.3	0.13[a]
P*S	2	0.4	0.65
P*M	1	0.1	0.74
S*M	2	0.0	0.98

* Denotes a statistically significant difference ($\alpha = 0.05$).
[a] One-tailed test of hypotheses that cover would increase with treatment.

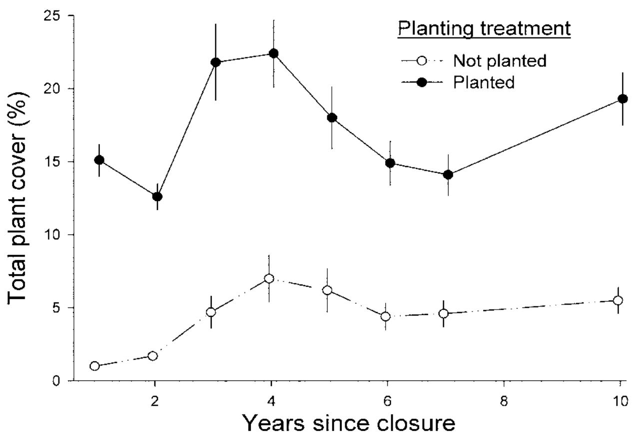

Figure 10. Effect of planting on plant cover.

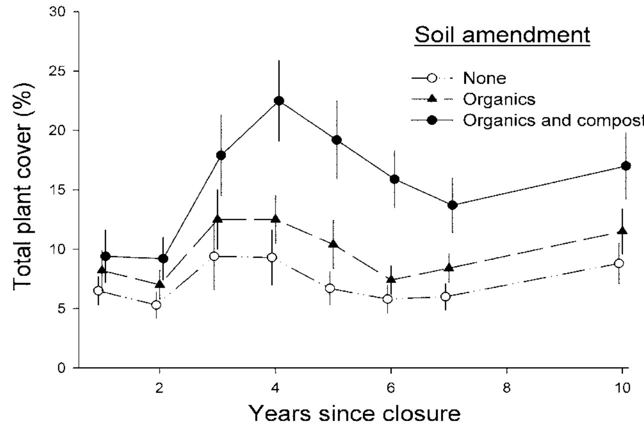

Figure 11. Effect of soil amendments on plant cover.

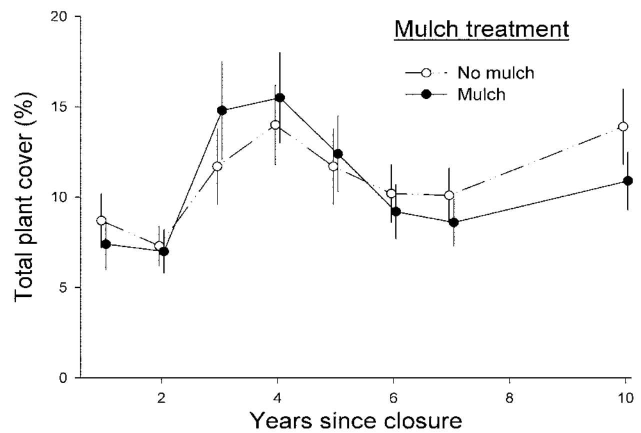

Figure 12. Effect of mulching on plant cover.

(19 percent) than on plots that were not planted (6 percent) (fig. 10).

Soil amendments were also effective, but to a lesser degree (table 4). Again, magnitude of effect varied with year since treatment, being least pronounced in the first years following closure (fig. 11). 10 years after treatment, plant cover on plots that received organics and compost amendments was significantly greater than on plots that received no amendments (adjusted Dunnett's multiple comparison, $t = 3.34$, $p = 0.01$). The plant cover on plots that were amended with organics only appeared greater than on plots that received no amendments, but differences were not statistically significant (adjusted Dunnett's multiple comparison, $t = 1.41$, $p = 0.16$). Differences between the organics and compost and organics only plots were also not statistically significant (adjusted Tukey-Kramer multiple comparison, $t = 1.93$, $p = 0.09$).

Mulching with a biodegradable mat did not have a significant effect on plant cover, over the entire length of the study (table 4), for 2005 (table 5), or for any other year (fig. 12).

Effects on Transplant Cover

Transplants differed from plants that grew from seed, both in temporal patterns of response and in the effectiveness of the restoration treatments. Although there was annual variation, the total cover of transplants after 10 years was comparable to their cover immediately after transplanting (fig. 13). As reported in detail in Cole and Spildie (2006), this temporal pattern resulted from growth in transplant size offsetting the mortality of individual transplants. In the first 7 years of the study, 32 percent of the transplants died; however, the mean area of survivors increased 39 percent.

Growth forms varied in response. The cover of small trees increased most, where they were planted, while the cover of shrubs decreased most (fig. 13). As Cole and Spildie (2006) report, most planted trees (79 percent) survived, and the size of the trees increased greatly (mean increase in area of 243 cm^2). Graminoids survived

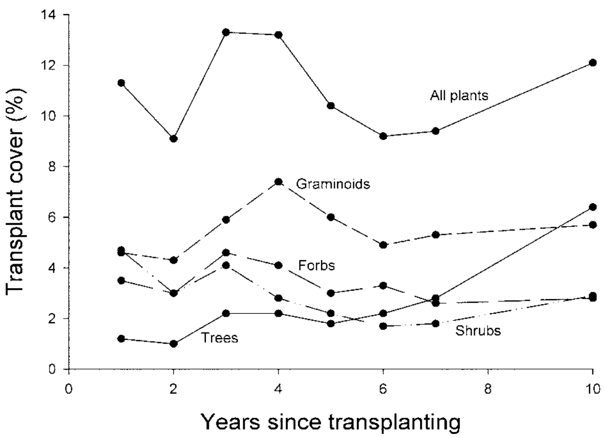

Figure 13. Change in cover of transplants since transplanting: all plants and growth forms.

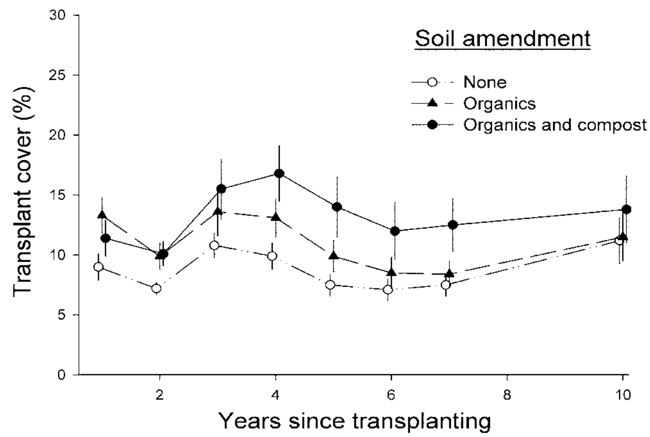

Figure 14. Effect of soil amendments on transplant cover.

most frequently (87 percent); they also grew substantially (mean of 56 cm^2). Forbs survived less frequently (72 percent) and grew more modestly (mean of 56 cm^2). Shrubs, in contrast, had poor survivorship (45 percent) and experienced little growth (mean increase in area of 0 cm^2).

Treatment effects—Beyond closure and transplanting, other restoration treatments had relatively little effect on plant cover. Mulch had no effect on transplant cover (table 6). Transplant cover did vary significantly among the soil amendments and there was no interaction between year and treatment (table 6). Overall, transplant cover on plots amended with organics and compost was significantly greater than on plots that were only scarified (adjusted Dunnett's multiple comparison, t = 2.46, p = 0.03). As Cole and Spildie (2006) report, amendments increased transplant growth rates but not survival. During the period of time between about two and 6 years after transplanting, it was possible to visually identify the composted plots by the large stature of many of the transplants. However, the magnitude of effect declined

Table 6. Effects of soil amendments and mulching on transplant cover, repeated measures analysis of variance results.

Effect	df	F	p
Soil amendment (S)	2	3.0	0.05*[a]
Mulch (M)	1	0.3	0.60
S*M	2	0.3	0.74
Year (Y)	7	8.8	<0.01*
Y*S	14	0.6	0.87
Y*M	7	1.4	0.20

* Denotes a statistically significant difference (α = 0.05).
[a] One-tailed test of hypothesis that cover would increase with treatment.

toward the end of the 10-year study (fig. 14). In 2005, plots amended with organics and compost did not have significantly more transplant cover than plots that were only scarified (adjusted Dunnett's multiple comparison, t = 0.89, p = 0.31) and these plots could no longer be easily identified visually, on the basis of transplant stature.

Graminoids were the only growth form for which transplant cover was significantly higher on organics and compost plots than on unamended plots (adjusted Dunnett's multiple comparison, t = 2.49, p = 0.04). Cole and Spildie (2006) report that graminoid transplant growth was also greatest on organics and compost plots.

Responses of individual species—Despite small sample size, some insight into the variable response of individual species can be gained (table 7). All seven of the *Achillea millefolium* transplants died. Otherwise, survivorship varied between 43 percent and 100 percent. Note that because only transplant cover was assessed in 2005, survivorship and change in size of individual transplant can only be estimated through 2002. Of the most abundant species, survivorship was notably high (100 percent) for *Juncus parryi* and *Carex rossii*. It was notably low for *Vaccinium scoparium* (45 percent) and *Phyllodoce empetriformis* (50 percent).

Of the eighteen species that survived to 2002, eight species grew substantially (increase in area of more than 20 percent), while six species declined substantially in size. The net effect of survivorship and growth is reflected in cover values in table 7. Cover increased over the 10-year period for nine species and decreased for 10 species. The species that increased most were trees and graminoids: *Pinus contorta, Abies lasiocarpa, Calamagrostis canadensis, Juncus parryi*, and *Carex rossii*. The species that decreased most were *Vaccinium*

Table 7. Responses of individual transplanted species.

Species	Number[a]	Survival[b] (%)	Survivor area (cm^2) 1995	Survivor area (cm^2) 2002	Cover[d] (%) 1996	Cover[d] (%) 2005
Abies lasiocarpa	8	63	66	121	1.1	1.6
Achillea millefolium	7	0	-	-	1.3	0.0
Antennaria alpina	8	50	117	41	1.0	0.1
Antennaria lanata	13	92	90	80	1.4	1.3
Aster alpigenus	8	100	76	19	2.0	0.5
Calamagrostis canadensis	7	86	144	142	0.7	3.3
Carex rossii	21	100	122	223	2.0	2.9
Danthonia intermedia	9	89	123	57	2.6	0.6
Festuca viridula	5	80	141	155	2.0	2.3
Hypericum formosum	8	50	174	46	1.1	0.3
Juncus parryi	40	100	199	278	2.6	4.0
Luzula hitchcockii	17	47	173	138	1.1	0.8
Oyzopsis exigua	6	100	227	198	2.2	1.5
Phyllodoce empetriformis	16	50	154	235	3.2	1.7
Pinus contorta	6	100	66	471	1.0	11.0
Polymonium pulcherrimum	6	83	64	164	0.6	1.2
Sibbaldia procumbens	18	89	125	220	1.9	2.3
Spiraea betulifolia	7	43	50	30	0.6	0.8
Vaccinium scoparium	69	45	135	114	3.1	2.0

[a] Number of individuals of each species that were originally transplanted.
[b] Percentage of original transplants that survived until 2002.
[c] Mean area of those original transplants that survived, in 1995 and 2002.
[d] Mean cover of all plots transplanted with the given species.

scoparium, Phyllodoce empetriformis, Danthonia intermedia, Aster alpigenus, and *Achillea millefolium.*

For the species that transplanted successfully, plants survived and grew well whether soils were amended or not. Nevertheless, in the case of both *Juncus parryi* and *Carex rossii,* growth rates were significantly greater on plots amended with either organics or organics and compost, in comparison to unamended plots (Cole and Spildie 2006).

Of the species that transplanted least successfully, it was possible to assess the effect of soil amendments on *Vaccinium scoparium* and *Phyllodoce empetriformis*. Soil amendments had little effect on the transplanting success of *P. empetriformis*. For *V. scoparium* transplants, soil amendments affected transplant survival but not growth (fig. 15). Survival was substantially greater on plots that received either of the soil amendment treatments, starting the fourth year following transplanting. Although differences between treatments were not significant when the entire length of the experiment is examined (Wilcoxon chi-square = 2.37, $p = 0.15$), they were significant in 2002 (Pearson chi-square = 4.62, $p = 0.05$), the last year transplants were counted. Despite increased survivorship, mean cover of *V. scoparium* transplants in 2005 was not significantly greater on organics and compost plots (2 percent) than on unamended plots (1.3 percent) (adjusted Dunnett's multiple comparison, $t = 0.56$, $p = 0.17$)

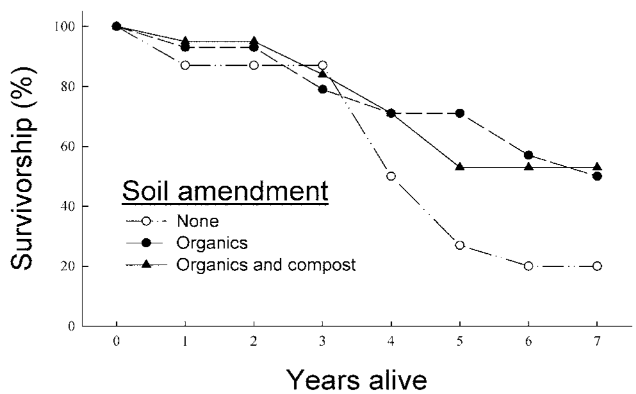

Figure 15. Effect of soil amendments on survivorship of *Vaccinium scoparium.*

Effects on Seedling Cover

In contrast to the total cover of transplants, the cover of plants that grew from seed (seedlings) doubled over 10 years (fig. 16). However, this increase was not consistent. Seedling cover increased almost threefold in the first 4 years following closure, declined substantially for the next 3 years and then increased slightly between 2002 and 2005. Both seeded species and volunteers exhibit this temporal pattern of response, although the increase in cover of volunteers has been more slow and steady. Cover of seeded species after 10 years was only

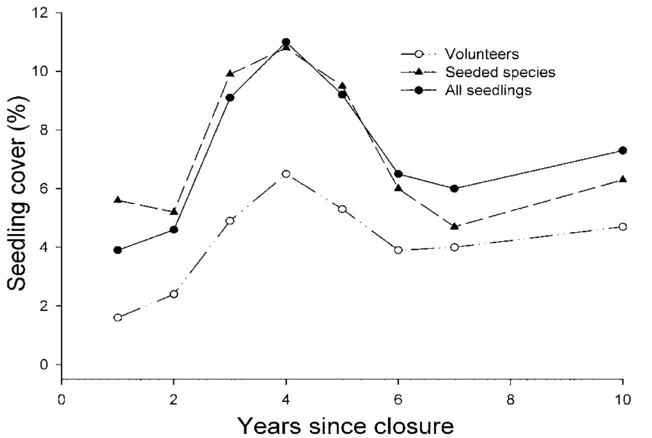

Figure 16. Change in seedling cover since campsite closure and seeding.

slightly greater than it was the first summer after seeding. Cover of volunteers was three times greater in 2005 than it was in 1996. In 1996, the cover of seeded species on plots that were seeded was 3.5 times the cover of volunteer species. In 2005, cover of seeded species was only 1.3 times the cover of volunteers. As reported in detail in Cole (in press), the density of seeded species was greatest in 1996, while the density of volunteers was greatest in 1998. Consequently, increases in cover reflect increases in the size of seedlings that more than offset seedling mortality.

Most seedling cover is provided by graminoids, while shrub and tree seedling cover is minimal (fig. 17). This partially reflects the fact that shrub and tree species were not seeded and that only graminoids were seeded on two of the sites. But graminoids and forbs were also the most abundant volunteer seedlings. Both graminoids and forbs increased in cover over the 10 years, but cover of tree seedlings declined. Although the cover of what we called shrub seedlings increased, many of these "seedlings" may have sprouted from roots rather than reproduced from seed. Consequently, we are hesitant to try to describe the response of shrub seedlings beyond noting that they remain negligible, even 10 years after closure. The variable temporal pattern of increasing cover is largely explained by the response of graminoids.

Only one non-native individual established on these plots, and it only survived for two seasons. Non-native species are largely absent at the elevation where these campsites are located; they are abundant along trails and on campsites at lower elevations (below 2000 m).

Treatment effects—Scarification had a small but positive effect on seedling cover. As noted earlier, plant cover on plots that were only scarified (all seedlings) was significantly greater than on plots that were not scarified. Cole (in press) reports that 7 years after closure, plant density on scarified plots was more than three times the density on plots that were not scarified. In terms of cover, however, the magnitude of difference was never more than a couple percent.

The more elaborate treatments varied substantially in effect. Application of the biodegradable mulch mat did not have a clear effect on the cover of seedlings. In contrast, seeding had a pronounced effect (table 8). Although magnitude of effect declined somewhat over the 10-year study, seeded plots had two times more seedling cover in 2005 than plots that were not seeded (fig. 18).

Results are less conclusive regarding the effect of planting treatments on the cover of volunteer seedlings. One might expect either increased success for volunteers on plots with transplants due to facilitation

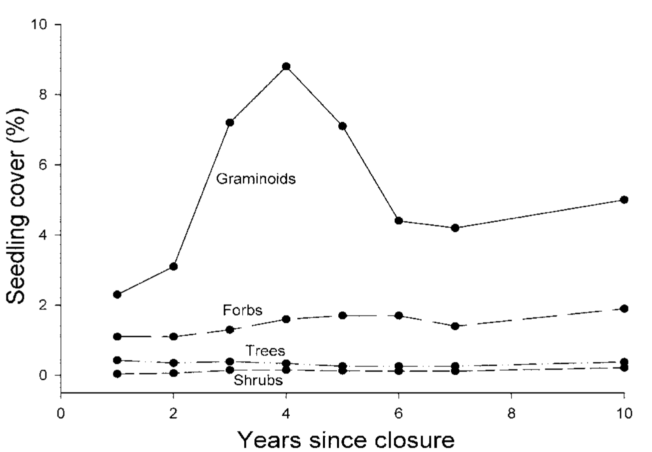

Figure 17. Change in seedling cover of different growth forms since campsite closure.

Table 8. Effects of seeding, soil amendments, and mulching on seedling cover, repeated measures analysis of variance results.[a]

Effect	df	F	p
Seeding (SD)	1	28.3	<0.01* [b]
Soil amendment (S)	2	3.8	0.03* [b]
Mulch (M)	1	0.0	0.92
SD*S	2	0.4	0.69
SD*M	1	0.4	0.55
S*M	2	0.8	0.47
Year (Y)	7	14.9	<0.01* [b]
Y*SD	7	1.6	0.15
Y*S	14	2.4	<0.01*
Y*M	7	0.7	0.65

* Denotes a statistically significant difference (α = 0.05).
[a] Higher order interactions were not significant and are not shown.
[b] One-tailed test of hypothesis that cover would increase with treatment.

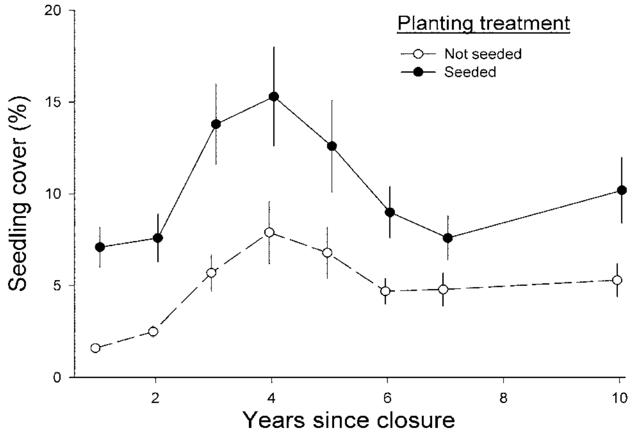

Figure 18. Effect of planting on seedling cover.

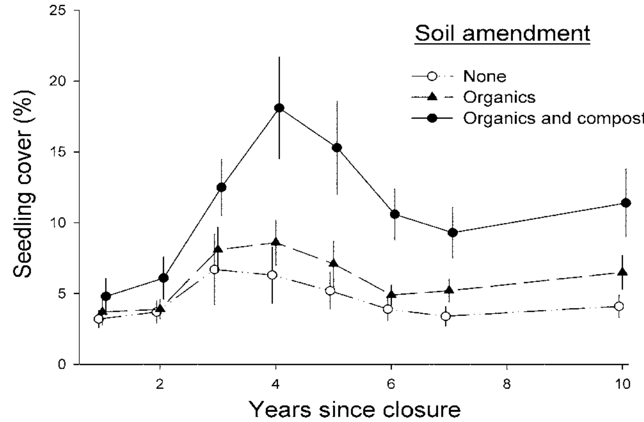

Figure 20. Effect of soil amendments on seedling cover.

(remember that seeded plots were also transplanted) or decreased success due to competition. Volunteer cover was consistently higher on plots that were not seeded, starting the third year after closure (fig. 19). However, this difference was not statistically significant over the entire length of the study (repeated measures analysis of variance, F = 1.95, p = 0.24) or in 2005 (univariate analysis of variance, F = 0.37, p = 0.57). Therefore, we cannot confidently conclude that planting decreased the cover of volunteer species. However, we also cannot be confident that planting does not have an adverse effect, given the results illustrated in figure 19. More detailed examination of the data indicates that volunteer cover was much higher on unplanted plots on only two of the campsites. Cole (in press) reported that the density of volunteers did not differ between planted and unplanted plots, suggesting that if there is an adverse effect of planting on volunteers, it is a reduction in size rather than density of plants.

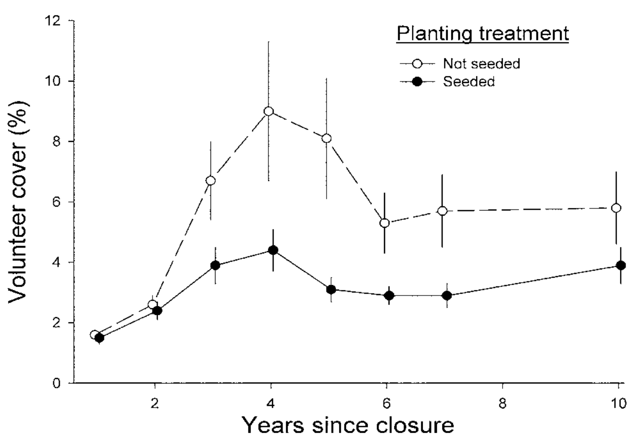

Figure 19. Effect of planting on cover of volunteers.

Amending soils also had a positive effect on seedling cover. The effectiveness of soil amendments varied over the course of the study (fig. 20), being least effective in the early years and most effective 4 or 5 years after treatment. Because the interaction with year since treatment was statistically significant (table 8), soil amendment effects are only evaluated in 2005, the final year of the study (table 9). In 2005, mean seedling cover on plots with organics and compost amendments was almost three times the seedling cover of unamended plots (adjusted Dunnett's multiple comparison, t = 2.37, p = 0.03). Cover on plots with the organics only treatment was not significantly different from either unamended plots (adjusted Dunnett's multiple comparison, t = 1.06, p = 0.13) or the organics and compost plots (adjusted Tukey-Kramer multiple comparison, t = 1.31, p = 0.20).

Responses of different species—Both seeded species and volunteers responded positively to the organics and compost soil amendment (table 10). Generally, graminoids and forbs responded positively to soil amendments, while tree seedlings did not (table 10).

Of the seeded species, only *Sitanion hystrix* did not establish well initially. It established at low densities

Table 9. Effects of seeding, soil amendments, and mulching on seedling cover in 2005.

Effect	df	F	p
Seeding (SD)	1	27.7	<0.01*[a]
Soil amendment (S)	2	2.8	0.05*[a]
Mulch (M)	1	0.6	0.50
SD*S	2	0.5	0.59
SD*M	1	0.3	0.61
S*M	2	0.4	0.67

* Denotes a statistically significant difference (α = 0.05).
[a] One-tailed test of hypotheses that cover would increase with treatment.

Table 10. Mean (s.e.) seedling cover in 2005, 10 years after treatment, on plots with various soil amendments.

	Soil amendment		
	None	Organics	Organics and compost
Seeded species	2.7 (1.3)	5.1 (2.3)	11.2 (4.5) [a]
Volunteers	3.0 (0.7)	4.4 (0.7)	6.7 (1.4) [a]
Graminoids	2.9 (0.7)	4.2 (0.8) [a]	7.9 (1.6) [a]
Forbs	0.4 (0.2)	1.6 (0.9)	3.8 (1.4) [a]
Tree seedlings	0.5 (0.1)	0.4 (0.1)	0.3 (0.1)

[a] Treatments that differ significantly from untreated plots.

on only two of six seeded plots and was absent on all plots 10 years later (table 11). The two additional seeded grasses, *Danthonia intermedia* and *Phleum alpinum*, established in abundance initially, but provided minimal cover 10 years later. *D. intermedia* survived on only one of six seeded plots, while *P. alpinum* survived on 10 of 18 seeded plots. Neither of these species is well represented in the undisturbed adjacent vegetation, however.

In contrast, the two most common graminoids in the undisturbed vegetation, *Juncus parryi* and *Carex rossii*, increased in cover over the 10-year period (table 11). *J. parryi* was seeded on three of the campsites. It volunteered on all campsites and on 38 of the 54 plots where it was not seeded. Although the density of seeded *J. parryi* declined from a maximum of 251 seedlings in 1996 to only 36 seedlings in 2002 (as reported in Cole in press), mortality was more than offset by growth of those plants that survived. 10 years after treatment, *J. parryi* seedling cover on seeded plots was 4 percent. Along with the 4 percent cover of *J. parryi* transplants, total cover of this species exceeded its mean cover of 6 percent in undisturbed vegetation within several years. On sites that were not seeded or transplanted, mean *J. parryi* cover was 1.1 percent. Although *J. parryi* transplants responded positively to soil amendment and Cole (in press) reports that the density of *J. parryi* seedlings was higher on amended soils, the cover of *J. parryi* seedlings did not vary significantly among soil amendments (repeated measures analysis of variance, $F = 0.22$, $p = 0.81$). In 2005, the mean cover of *J. parryi* seedlings was 2.6 percent on unamended plots, 1.9 percent on organics plots, and 3.6 percent on organics and compost plots.

Carex rossii volunteered on 69 of the 72 plots that were at least scarified. Within 3 years, *C. rossii* cover exceeded the 1 percent cover typical of undisturbed sites. 10 years after closure, mean *C. rossii* cover was 3.1 percent. *C. rossii* cover responded positively to both soil amendments. In 2005, mean cover of *C. rossii* was 1.2 percent on non-amended plots, 3.2 percent on organics plots, and 4.7 percent on organics and compost plots (adjusted Dunnett's multiple comparison, $t = 2.18$, $p = 0.05$ for the difference between non-amended and organics plots and $t = 3.37$, $p < 0.01$ for the difference between non-amended and organics and compost plots). Differences between organics and organics and compost plots were not statistically significant (adjusted Tukey's multiple comparison, $t = 1.17$, $p = 0.25$).

Forbs responded less variably. *Aster alpigenus* and *Sibbaldia procumbens* both established in modest numbers on virtually all the plots on which they were seeded. Density of these species has declined precipitously (Cole in press), but cover in 2005 is still about 50 percent of their maximum cover (reached the first year after seeding) and not different from typical cover on undisturbed sites. *Antennaria alpina* and *Penstemon globosus* established in much greater abundance and, despite declining density, have increased in cover over the 10 years. Although sample size is too small for statistical analysis, both of these species appear to have responded

Table 11. Mean cover (percent)[a] at the end of each growing season for seeded species and the most abundant volunteers.

	1996	1997	1998	1999	2000	2001	2002	2005
Antennaria alpina—seeded (n=12)	2.0	0.9	1.5	2.2	3.0	3.4	3.0	4.9
Antennaria alpina—volunteer (n=5)	0.2	0.4	0.6	0.7	1.0	1.4	2.3	2.1
Antennaria lanata—seeded (n=6)	0.4	0.4	0.3	0.9	0.5	1.1	0.7	1.5
Aster alpigenus—seeded (n-6)	0.7	0.5	0.5	0.5	0.5	0.5	0.5	0.3
Danthonia intermedia—seeded (n=6)	1.8	1.4	0.5	0.6	0.3	0.5	0.3	0.1
Juncus parryi—seeded (n=17)	1.3	1.6	2.9	3.6	3.3	2.7	2.6	4.1
Juncus parryi—volunteer (n=37)	0.3	0.4	0.7	1.0	1.0	0.7	0.9	1.1
Penstemon globosus—seeded (n=6)	3.7	2.3	4.6	7.4	5.6	6.4	5.1	8.2
Phleum alpinum—seeded (n=18)	4.3	4.7	10.7	9.9	8.2	2.3	1.1	0.1
Sibbaldia procumbens—seeded (n=11)	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.3
Sitanion hystrix—seeded (n=2)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0
Carex rossii—volunteer (n=69)	0.5	1.0	2.7	3.3	2.5	2.2	2.2	3.1

[a] Mean cover on plots where the species established (n).

Figure 21. Abundunt large *Penstemon globosus* seedlings on plot amended with organics and compost, 6 years after treatment.

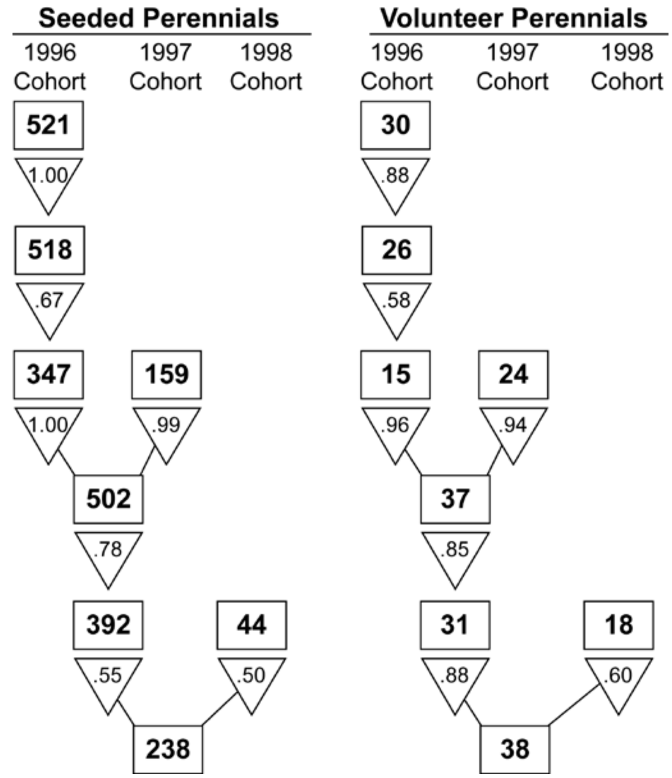

Figure 22. Seedling density (#/m^2, in squares) and survival rates (in triangles) of seeded species and volunteers from cohorts of seedlings that established in 1996, 1997, and 1998. Densities are for early and late summer of each year and survival for intervening periods.

favorably to the soil amendments. In 2005, mean cover of *A. alpina* was 0.6 percent on non-amended plots, 2 percent on organics plots, and 5.5 percent on organics and compost plots. In 2005, mean cover of *P. globosus* was 0.5 percent on non-amended plots, 6.2 percent on organics plots, and 15.0 percent on organics and compost plots (fig. 21). *Antennaria lanata* established at more modest densities but also increased in cover. It also appears to have responded favorably to soil amendments. In 2005, mean cover of *A. lanata* was 0.5 percent on non-amended plots, 1.2 percent on organics plots, and 1.4 percent on organics and compost plots.

Seedling Establishment and Mortality

Additional insights into seedling response to restoration can be gleaned from the more frequent and detailed assessments of seedlings that were conducted the first 3 years following restoration. Seedlings became established throughout the two-month assessment period (early July to early September), but two-thirds of the seedlings became established (cotyledons were well-developed) in early August—about one month after snowmelt. On seeded plots, the number of newly established seeded species declined greatly each year, from 521/m^2 the first year, to 159/m^2 the second year and 44/m^2 the third year (fig. 22). The number of newly established volunteers declined from 30/m^2 the first year, to 24/m^2 the second year, and 18/m^2 the third year.

Mortality rates during the growing season, once seedlings were established (had well-developed cotyledons), were very low for the first two seasons (less than 1 percent for seeded species and 5 to 12 percent for volunteers) (fig. 22). Overwinter mortality rates were higher (22 to 33 percent for seeded species and 15 to 42 percent for volunteers). Mortality of seeded species was much higher during the third growing season (45 percent), the first hot, dry summer without supplemental watering (supplemental watering occurred the first summer; the second summer was cool, with frequent precipitation). Mortality of volunteers during the third growing season was also higher than in early years but much less than for seeded species (22 percent). Only 33 percent of the established seedlings of seeded species survived three growing seasons, while 53 percent of the established seedlings of volunteers survived. Consequently, the proportion of seedlings that were volunteers increased from 5 percent after the first growing season to 14 percent at the end of the third growing season. This proportion had increased to 20 percent after 7 years.

For the first three seasons it was possible to distinguish treatment effects on seedling establishment rates from effects on mortality rates. In each of the first three seasons, the number of seedlings that established was much greater on seeded plots than on plots that were not seeded (table 12 and fig. 22), but neither the mulch nor the soil amendments affected natality rates.

As noted before, mortality rates were generally low the first two seasons. Mortality rates were significantly higher on plots that were not planted for the first 2 years (table 13), reflecting the fact that mortality rates were higher for volunteers than for seeded species those years (fig. 22). In 1998, however, the summer was hot and dry and plants were not watered. Mortality rates were much higher that summer (fig. 22). Under these conditions, seeded plots experienced much greater mortality (33 percent) than plots that were not seeded (17 percent) (tables 13 and 14). Higher mortality on seeded plots did little to offset the greater establishment rate on seeded plots. Seedling density on seeded plots was more than five times the density on non-seeded plots after three growing seasons (Cole in press).

Plots amended with organics and compost experienced much lower mortality rates (13 percent) than plots amended with organics only (23 percent) and plots without amendments (33 percent) (table 13 and 14). As reported by Cole (in press), seedlings growing in plots amended with organics and compost grew much more rapidly than seedlings that did not receive this treatment. Both root and shoot biomass of seedlings was significantly greater in plots amended with organics and compost, both in 1996 and in 1997 (table 15).

Table 12. Effects of seeding, soil amendments, and mulching on seedling natality (density of newly established seedlings) in each of the first three years after treatment.

		1996		1997		1998	
Effect	**df**	**F**	**p**	**F**	**p**	**F**	**p**
Seeding (SD)	1	16.4	<0.01*	3.5	0.03*[a]	8.9	<0.01*
Soil amendment (S)	2	0.6	0.57	0.5	0.59	0.7	0.50
Mulch (M)	1	0.4	0.53	0.9	0.34	0.2	0.63
SD*S	2	1.0	0.38	0.3	0.76	1.1	0.35
SD*M	1	0.5	0.50	0.1	0.80	0.6	0.46
S*M	2	1.3	0.28	0.6	0.54	0.7	0.50

* Denotes a statistically significant difference ($\alpha = 0.05$).
[a] One-tailed test of hypothesis that nataility would increase with treatment.

Table 13. Effects of seeding, soil amendments, and mulching on seedling mortality in each of the first 3 years after treatment.

		1996		1997		1998	
Effect	**df**	**F**	**p**	**F**	**p**	**F**	**p**
Seeding (SD)	1	5.4	0.02*	6.5	0.01*	4.7	0.04*
Soil amendment (S)	2	0.2	0.83	2.3	0.10	2.9	0.03*[a]
Mulch (M)	1	1.0	0.32	0.0	0.86	1.6	0.20
SD*S	2	0.1	0.92	1.3	0.29	0.1	0.92
SD*M	1	0.2	0.63	0.0	0.87	0.2	0.63
S*M	2	0.4	0.64	0.0	0.99	1.1	0.34

* Denotes a statistically significant difference ($\alpha = 0.05$).
[a] One-tailed test of hypothesis that mortality would decrease with treatment.

Table 14. Mean (s.e.) percent mortality of seedlings in each of the first 3 years after treatment.

	Soil amendment			Seeding treatment	
	None	**Organics**	**Organics and compost**	**Not seeded**	**Seeded**
1996	13(3)	14(4)	12(4)	16(3)	8(2) [a]
1997	14(5)	3(3)	12(6)	14(4)	3(1) [a]
1998	33(7)	23(4)	13(3) [a]	17(3)	32(6) [a]

[a] Treatments that differ significantly from untreated plots.

Table 15. Root and shoot biomass, mean (s.e.) on plots with different soil amendment treatments.

	Soil amendment		
	None	Organics	Organics and compost
1996 root biomass (mg)	1.7 (0.3)	1.9 (0.4)	3.4 (0.7) [a]
1996 shoot biomass (mg)	3.7 (1.1)	6.1 (1.6)	8.6 (2.0) [a]
1997 root biomass (mg)	30 (14)	38 (3)	112 (29) [a]
1997 shoot biomass (mg)	71 (42)	62 (18)	231 (66) [a]

[a] Amended plots that differed significantly from non-amended plots.

Because we mapped all seedlings that established for the first 2 years, it was also possible to assess the effect of transplants on seedling establishment and survival. As noted earlier, the density of volunteers on transplanted plots was not significantly different from density on plots that were not planted. This suggests that transplants have little effect on seedling establishment and survival, either positive or negative. To explore relationships further, we compared seedling density within the canopy of transplants to density outside the canopy. Two years after seeding, seedling densities were significantly lower within the canopy (paired t-test, $t = 2.35$, $p < 0.01$). We then assessed whether seedlings tended to establish close to, or far from, transplants. This was accomplished by calculating the distance from seedlings to the nearest transplant, as well as the mean distance from 100 random points to the nearest transplant. The differences between these distances was calculated and averaged. On average, seedlings were located 1.1 cm closer to transplants than expected, but this difference was not statistically significant (one-sample t-test, $t = 1.72$, $p = 0.10$).

Effects on Species Richness

10 years after treatment, the mean 1 m^2 plot had four species. At the scale of the entire campsite, mean species richness for the six closed campsites was 13 species. This is comparable to the mean of 15 species found on undisturbed reference sites. Treatments varied greatly in their effectiveness in restoring species richness. Plots that were scarified (but not treated in any other way) had significantly more species (mean of 1.8 species, s.e. = 0.5) than plots that were not scarified (mean of 0.7 species, s.e. = 0.3) (one-tailed t-test, $t = 1.83$, $p = 0.05$). Of the more elaborate treatments, only planting was effective in increasing species richness (table 16). At the plot level of analysis, mean (s.e.) species richness was 2.2 (0.5) species on unplanted plots and 6.3 (0.4) species on planted plots. At the campsite level of analysis, species richness was 5.0 (0.7) species on unplanted plots and 11.2 (1.4) species on planted plots.

Progress in Relation to Reference Conditions

Clearly, progress has been made in restoring both the soil and vegetation on these campsites. However, degree of progress varied among treatments and among sites, as well as among the measures of progress that we employed. To assess progress, it is helpful to compare conditions on the closed campsites to campsite conditions prior to campsite closure and to reference conditions on undisturbed control sites.

As illustrated in figure 7, amendment of campsite soil with organics and compost resulted in near-complete restoration of the soil characteristics we examined. Soils on these plots did not differ significantly from undisturbed controls, while all characteristics were higher than on unrestored portions of the campsite. In contrast, plots that were scarified only showed little recovery. Soils on these plots generally differed significantly from undisturbed controls and were not different from soils on unrestored portions of the campsite. Plots amended with organics only were intermediate, but more similar to those that were scarified only. It is important to remember, however, that if we had assessed physical characteristics of the soil (such as porosity or infiltration rates), both degree of progress and the relative success of the different treatments might be different.

The 12 percent mean vegetation cover on campsites, 10 years after closure, represents substantial progress in vegetation recovery compared to the 0 percent cover that typified these campsites prior to closure. However, vegetation cover is still far from the 50 percent cover that is

Table 16. Effects of planting, soil amendments, and mulching on species richness in 2005.

Effect	df	F	p
Planting (P)	1	87.7	<0.01*[a]
Soil amendment (S)	2	0.5	0.32[a]
Mulch (M)	1	0.3	0.30[a]
P*S	2	0.2	0.79
P*M	1	0.1	0.71
S*M	2	0.2	0.81

* denotes a statistically significant difference ($\alpha = 0.05$).
[a] One-tailed test of hypotheses that richness would increase with treatment.

Figure 23. Plot that was planted and amended with organics and compost, with 50 percent cover after 7 years.

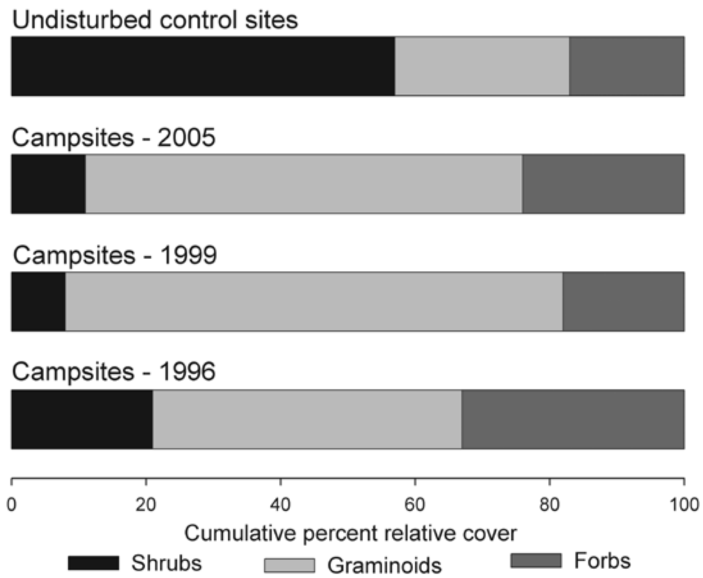

Figure 24. Relative cover of growth forms on closed campsites and undisturbed control sites.

typical of undisturbed sites. Progress varied both among campsites and among treatments. On plots that were given the most effective treatments (scarified, planted, and amended with organics and compost), mean cover after 10 years was 27 percent, about one-half of the cover of reference sites. On one of the campsites, plots that were given this treatment were at 50 percent cover after 10 years (fig. 23).

In addition to interest in increasing vegetation cover, we were also interested in restoring vegetation similar in composition to undisturbed conditions. As illustrated in table 17, most of the vegetation on the closed campsites was herbaceous. This contrasts sharply with composition of the groundcover on undisturbed sites. Shrubs accounted for 57 percent of the cover on undisturbed sites but only about 11 percent of the cover on the campsites in 2005 (fig. 24). In the undisturbed vegetation, graminoids accounted for 26 percent of the cover; on the campsites they accounted for 65 percent of the cover. Finally forbs made up 17 percent of the cover of undisturbed vegetation and 24 percent of the cover on campsites. Campsite composition was most similar to reference conditions immediately after the restoration treatments (table 17 and fig. 24). Dissimilarity increased to a maximum in 1999, when total cover also peaked, and has declined since.

Most treatments were not beneficial in restoring the native species composition. Transplanting was the only effective way of establishing shrubs on the sites. However, even on plots that were planted and received the organics and compost treatment, the vegetation was 12 percent shrubs, 53 percent graminoids, and 35 percent forbs. Shrubs comprised about 40 percent of the vegetation cover on planted plots on two of the campsites (fig. 25), but were virtually absent on two of the other sites.

Of the 13 species with a mean cover of more than 0.1 percent on undisturbed sites, only *Carex rossii, Antennaria alpina*, and *Sibbaldia procumbens* had similar cover levels when all treatments are included (table 18). On plots that were planted and amended with organics and compost, *Juncus parryi, Pinus contorta*, and *Luzula hitchcockii* also were surviving at levels at least equal to those on reference sites. In contrast, even on transplanted and composted sites, *Vaccinium*

Table 17. Variation in cover of different growth forms on campsites over the 10-year study.

	1996	1997	1998	1999	2000	2001	2002	2005
Graminoids	4.6	5.3	10.2	12.5	10.1	6.9	6.9	7.9
Forbs	3.3	2.1	2.9	3.0	2.7	2.8	2.3	2.9
Shrubs	2.0	2.1	1.8	1.4	1.0	0.8	0.9	1.4
Trees	0.6	0.6	0.8	0.6	0.6	0.6	0.7	1.4

Figure 25. Unusually luxuriant growth of *Vaccinium scoparium* and *Phyllodoce empetriformis* transplants after 7 years.

scoparium and *Phyllodoce empetriformis* had mean cover of 2.5 percent and 0.4 percent, respectively. On reference sites, these species have mean cover of 27 percent and 7.1 percent, respectively. Of the less common species, planting resulted in coverages that exceeded those on reference sites for all species other than *Gaultheria humifusa, Achillea millefolium*, and *Sitanion hystrix* (table 18).

Forty-one different species appear to have volunteered on closed campsites (table 19). However, as many as 10 of these species may be incorrectly classified as volunteers, either because they were overlooked in transplanted plugs or because they sprouted from roots of established plants. About half of the species that volunteered were species that we planted on the sites. Twenty species volunteered only on closed campsites.

On average, we transplanted and/or seeded six or seven different species on each campsite. After 10 years, the mean number of species growing on campsites was 13. This level of species richness is close to the mean of 15 species growing on undisturbed control sites.

Discussion

The treatments we applied to these highly disturbed campsites were partially successful in restoring these sites. There has been significant progress in soil and vegetation recovery, particularly on those plots that were planted and amended with organics and compost. Some soil impacts have also been mitigated. Vegetation

Table 18. Mean percent cover of planted species on all campsite plots, plots that were planted and amended with organics and compost, and undisturbed reference sites.

Species	Number of camps	All treatments	Planted and composted	Undisturbed
Vaccinium scoparium	5	1.0	2.5	27.0
Phyllodoce empetriformis	3	0.4	0.4	7.1
Juncus parryi	6	3.1	6.2	5.2
Abies lasiocarpa	4	0.4	0.5	4.1
Pinus contorta	4	1.0	1.8	1.7
Carex rossii	6	2.6	5.2	1.5
Antennaria lanata	3	0.3	0.8	1.4
Antennaria alpina	2	0.9	2.8	0.8
Festuca viridula[a]	2	0.1	0.3	0.8
Veronica cusickii[a]	3	0.1	0.1	0.8
Sibbaldia procumbens	3	0.5	1.8	0.5
Gaultheria humifusa[a]	0	0	0	0.4
Luzula hitchcockii	2	0.2	0.3	0.3
Achillea millefolium	0	0	0	<0.1
Aster alpigenus	1	0.1	0.2	<0.1
Calamagrostis canadensis	1	0.3	0.8	<0.1
Danthonia intermedia	2	0.1	0.2	<0.1
Hypericum formosum	1	<0.1	<0.1	<0.1
Oryzopsis exigua	1	0.1	0.4	<0.1
Polemonium pulcherrimum	1	0.1	0.4	<0.1
Spiraea betulifolia	1	0.1	0.3	<0.1
Penstemon globosus	1	0.7	2.5	<0.1
Phleum alpinum	3	0.4	0.4	<0.1
Sitanion hystrix	0	0	0	<0.1

[a] Species that were unintentionally and non-systematically transplanted.

Table 19. Species that volunteered—the number of camps and percent of plots where they established, as well as mean percent cover, in 2005.

Species	Number of camps	Plot frequency	Mean cover
Carex rossii	6	96	3.0
Juncus parryi	6	53	0.5
Muhlenbergia filiformis	5	42	0.3
Vaccinium scoparium[a]	5	28	0.2
Pinus contorta	6	65	0.1
Picea engelmannii	5	60	0.1
Antennaria alpina	3	21	0.1
Polygonum kellogii	2	17	0.1
Carex phaeocephala	3	13	0.1
Carex microptera	1	3	0.1
Abies lasiocarpa	3	26	<0.1
Lewisia pygmaea	3	15	<0.1
Erigeron peregrinus[a]	3	6	<0.1
Gayophytum ramosissimum	2	14	<0.1
Polemonium pulcherrimum	2	10	<0.1
Sibbaldia procumbens	2	10	<0.1
Hieracium gracile[a]	2	6	<0.1
Luzula hitchcockii[a]	2	3	<0.1
Spraguea umbellata	1	10	<0.1
Calamagrostis canadensis[a]	1	6	<0.1
Linanthastrum nuttallii	1	3	<0.1
Penstemon fruticosus	1	3	<0.1
Veronica cusickii[a]	1	3	<0.1
Epilobium angustifolium	1	1	<0.1
Festuca viridula[a]	1	1	<0.1
Hypericum formosum[a]	1	1	<0.1
Juncus mertensianus	1	1	<0.1
Ligusticum tenuifolium	1	1	<0.1
Oryzopsis exigua	1	1	<0.1
Penstemon globosus	1	1	<0.1
Phleum alpinum	1	1	<0.1
Polygonum phytolaccaefolium	1	1	<0.1
Spiraea betulifolia[a]	1	1	<0.1
Aster alpigenus	2	4	0
Antennaria lanata	2	3	0
Sagina saginoides	1	3	0
Castilleja chrysantha[a]	1	1	0
Cerastium vulgatum	1	1	0
Luzula campestris	1	1	0
Rorippa islandica	1	1	0
Sitanion hystrix	1	1	0

[a] Plants of these species may have been transplants or sprouts rather than volunteers.

cover has increased and many species have been reestablished on the sites. However, total vegetation cover remained diminished after 10 years (fig. 26). Even more problematic is the minimal cover provided by shrubs, particularly *Vaccinium scoparium* and *Phyllodoce empetriformis*. Neither of these species responded well to the treatments we applied. Transplanting helped, but more than one-half of the shrub transplants died and the soil amendments did not result in increased growth.

Treatment Effects

Most of the treatments contributed to recovery. Little recovery would have occurred if campsites had not been effectively closed to all human entry. Conversely, closure alone was not very effective. Mean cover on plots that were closed to use but not scarified was 0.5 percent after 10 years. Scarification was effective in promoting recovery, but as with closure, it is not sufficient. Mean cover on plots that were only scarified was 2.5 percent after 10 years.

Mulch blankets—Surprisingly, the mulch blankets had no appreciable effect, despite the fact that they are frequently employed and recommended (Urbanska and Chambers 2002) and have been shown to be effective in research conducted in other high-elevation ecosystem types (Petersen and others 2004). Fattorini (2001) reported that mulch blankets on ski runs in the Alps had

Figure 26. After 10 years of recovery, cover has increased, but is still sparse.

along with our root and shoot biomass measurements, show that while this amendment had no effect on germination and establishment rates, it benefited seedlings by making them less prone to mortality after they had become established. For the first 2 years, at least, seedlings growing in soil amended with organics and compost had much larger shoots and root systems than seedlings growing in soil that did not receive this amendment (fig. 27). This suggests that much of the beneficial effect of this treatment came from the nutritional input of the compost.

The effect of the additional nutrients in the compost on transplants was visually obvious, particularly 2 to 5 years after transplanting. As reported in Cole and Spildie (2006), transplants growing in plots amended with organics and compost were unusually large. By 2005, presumably because the additional nutrients supplied by the compost had been depleted, transplants on composted plots were no longer visually larger. Perhaps the most important long-term beneficial effect of this treatment was increased survivorship for *Vaccinium scoparium* transplants. Reestablishment of *V. scoparium* is both the most important and the most challenging aspect of restoring these sites. Any treatment that has a positive effect is important.

Results regarding the effectiveness of the amendment of soils with local organic matter, peat moss, and

no effect on transplant survival. Their primary effect was a reduction in flowering. In our study, lack of effect may reflect the unusually good growing conditions that existed for the first two summers. Survival of both transplants and seedlings was extremely high in these seasons. By the third summer, when hotter and drier conditions prevailed, the mats had already disintegrated. While they were not worthwhile under our working conditions, we are reluctant to conclude that they would not be worthwhile under other circumstances. More research on mulch mats is needed. They can also have other beneficial effects, such as deterring recreational use of the site and reducing erosion on steep slopes.

Soil amendments—The organics and compost soil amendment was clearly effective in accelerating recovery. It was effective in raising levels of organic carbon and potentially mineralizable nitrogen, and increasing microbial activity in soils where these characteristics had been adversely affected by decades of disturbance and lack of organic inputs (fig. 7). These changes, perhaps along with other unmeasured changes (such as bulk density, porosity, and water holding capacity), likely explain the higher levels of vegetation cover on plots given this amendment. Numerous other studies, conducted in diverse ecosystems (such as Caravaca and others 2002), have reported positive effects of compost on restoration success.

This amendment was more effective in promoting the cover of seedlings than of transplants. Our careful monitoring of seedling establishment and mortality,

Figure 27. Unusually large *Phleum alpinum* seedlings on plots amended with compost, 2 years after treatment.

native soil inoculum (but no compost) are less conclusive. This amendment was an attempt to reintroduce native soil biota and ameliorate some of the adverse physical properties of campsite soils, by increasing water holding capacity and reducing susceptibility to compaction but to not ameliorate the reduced levels of plant-available nitrogen on campsite soils. For virtually every measure of soil characteristics and vegetation response, values for plots with this amendment were intermediate between those for plots that were not amended and plots that were amended with organics and compost. In 2005, total cover on organics plots was 1.3 times the cover on unamended plots. Seedling cover was 1.6 times as high, while transplant cover was not different. These results are in line with our expectations. However, for most of our measures of response, differences between this treatment and the other two treatments were not statistically significant at an alpha level of 0.05. For effects on total cover and seedling cover, p-values were 0.16 and 0.13, respectively.

Therefore, we cannot conclude with a high degree of confidence that addition of local organic matter was beneficial. Conversely, the power of statistical tests was low, given our small sample size and substantial variation among the six campsites. Consequently, we also cannot conclude with a high degree of confidence that the increased cover observed on plots that received the organics amendment is not the result of the treatment. The beneficial effects we can be most confident about (differences were statistically significant at an alpha of 0.05) are increased organic carbon and total nitrogen in the soil, survival of *Vaccinium scoparium* transplants, growth of *Carex rossii* transplants and density of *Carex rossii* seedlings.

Seeding and transplanting—Both seeding and transplanting were effective. On plots that were both seeded and transplanted, mean cover of volunteers after 10 years was 3.9 percent. Seeding added another 6.3 percent, while transplanting added another 12 percent for a total of 20.2 percent cover on transplanted and seeded plots. On plots that were not seeded and transplanted, mean cover after 10 years (all volunteers) was 5.8 percent. Transplants had little effect, either positive or negative, on seedlings when planted at the densities at which we planted them. The fact that seedling density was lower within transplant canopies suggests that transplanting might inhibit seedling establishment if planted more densely.

Treatments and recovery rates—Table 20 provides a means for comparing the effectiveness of different treatments in various combinations. It assumes a linear extension into the future of the recovery rates that occurred over the past 10 years, reporting the number of years it would take to restore the target condition of 50 percent vegetation cover. Although future recovery rates are unlikely to be equivalent to rates during the first 10 years, the table emphasizes the lengthy recovery periods required regardless of treatment, as well as the need to apply intensive treatments if we intend to restore these sites within our lifetime. By working the soil, recovery time can be reduced to about 50 years, while with the addition of planting it can be reduced to about 20 years (table 20). Of the planting treatments, seeding is more effective than transplanting in reducing recovery time where soils are amended. In the absence of soil amendments (table 21), transplanting is more effective than seeding in reducing recovery time; however, in the absence of soil amendments, recovery time exceeds 30 years even with both seeding and transplanting.

Our evaluation of treatment effectiveness changes, however, if our criterion for success is the reestablishment of native species composition. Treatments were much more effective in restoring species richness than in restoring cover. The mean number of species on campsites was 13, close to the 15 species that is typical of undisturbed sites. Seeding and transplanting were by far the most effective treatment. Scarification had a small but statistically significant positive effect, but mulching and amending soils had no effect.

Table 20. Estimated time (in years) to recovery of 50 percent vegetation cover, assuming linear extrapolation of the past 10 years.

	Years to recovery
Closure	1000
+ scarification	200
+ mulch mat	200
+ organics	100
+ compost	56
+ seeding	31
+ transplanting	19
Transplanting, but not seeding[a]	36

[a] On plots with organics and compost amendments.

Table 21. Estimated time (in years) to recovery of 50 percent vegetation cover, without soil amendments, assuming linear extrapolation of the past 10 years.

	Years to recovery
Closure + scarification	200
+ seeding	84
+ transplanting	34
Transplanting, but not seeding	4

Treatments were less effective in restoring the native species composition of these sites than in restoring cover. After 10 years, shrub cover was only 11 percent, compared to 57 percent on reference sites. The most abundant species on reference sites, *Vaccinium scoparium* and *Phyllodoce empetriformis,* had mean cover on campsites of only 2.5 percent and 0.4 percent, respectively. Of the treatments, transplanting was by far the most effective for establishing these species. The only *P. empetriformis* plants on the campsites after 10 years were transplants. We observed a few small *V. scoparium* plants that were not transplants (probably stem sprouts rather than seedlings), but virtually all *V. scoparium* cover is provided by transplants. In combination with transplanting, the soil amendments may also be effective because more *V. scoparium* transplants survived on amended soils.

Further Research

It is important to remember that these general categories of treatment (such as planting and soil amendment) refer to very specific treatments. If we had used different planting treatments (different species, larger or smaller transplants, more transplants, more or less seed) results would have been at least quantitatively different. Further experimentation with planting techniques would be worthwhile. Particularly useful would be experimentation with planting of established plants grown from seed in nurseries. Theoretically it should be possible to reduce recovery time greatly by planting transplants at densities several times greater than the five to seven transplant plugs per square meter used in this study. Experimentation with dense plantings of *Vaccinium scoparium* and *Phyllodoce empetriformis*, both of which survived no more than half the time, would be particularly useful.

Opportunities for further experimentation with soil amendments are even more diverse. As noted earlier, amendments can serve to ameliorate the adverse effects of camping both on soil physical properties and on nutritional properties. Applying locally-derived organic matter of differing types and quantities could be tried. Highly-decomposed organics might be particularly effective in increasing water-holding capacity and reducing the tendency for scarified soils to become compacted by rainfall and snow loading. Materials such as long pine needles, twigs and small branches might be effective in promoting water infiltration into soils. Other sources of long-lasting supplemental nutrition, released in small quantities, could be employed. For example, Paschke and others (2000) report that the organic fertilizer Biosol® was effective in promoting plant growth on roadcuts. The depth of scarification and depth to which amendments are mixed could also be varied. Finally, it would be worthwhile to replicate the treatments applied in this study, in different places, to assess if the results are site-specific.

Treatment Needs of Individual Species

Individual species varied greatly in how easy they were to restore to reference conditions. This study provided substantial insight into the treatments necessary to effectively restore the most abundant species.

Graminoids—*Juncus parryi* and *Carex rossii,* the most abundant graminoids, transplanted well. Every transplant of these species survived and grew substantially (Cole and Spildie 2006). *J. parryi* also established well when seeded and a modest number of seedlings volunteered. These seedlings survived in sufficient quantities to approximate target conditions after 10 years. Although *C. rossii* was not seeded, it volunteered profusely, exceeding target conditions after 10 years. Results suggest that transplanting may be unnecessary for these species and even seeding may be unnecessary for *C. rossii*. However, *C. rossii* established and survived much more frequently on plots with either of the soil amendments, suggesting that amendment with organics is important if this species is left to reestablish on its own (fig. 28).

Forbs—The most abundant forbs planted were *Antennaria lanata, Antennaria alpina*, and *Sibbaldia procumbens*. Both *A. lanata* and *S. procumbens* became well-established only where they were planted. Both

Figure 28. Abundant *Carex rossii* seedlings that volunteered on plots amended with organic matter.

Figure 29. Percent cover of the *Pinus contorta* transplant on this plot increased 15-fold in 10 years.

species established well from transplants and seed, although *A. lanata* established particularly well from seed. Transplanting was more effective for *S. procumbens*. *A. alpina* transplants often did not survive or grow well. However, this species established prolifically from seed. In fact, it volunteered often enough to suggest that seeding may be unnecessary. For each of these species, cover was greater on amended plots than on plots that were not amended. Where they were planted, *S. procumbens* reached its target coverage even on unamended plots, *A. alpina* reached its target only on amended plots (either amendment), and *A. lanata* did not reach its target on any treatment. *Veronica cusickii,* the most abundant forb not intentionally planted, established only in the plugs we transplanted on the campsites.

Trees—Most of the small trees that we transplanted survived and grew well, particularly *Pinus contorta* (fig. 29). Seedlings of *P. contorta, Abies lasiocarpa,* and *Picea engelmannii* volunteered in substantial numbers but growth rates were so low that cover after 10 years was negligible. Soil amendments had no effect on either transplants or tree seedlings.

Shrubs—The most difficult species to establish were the shrubs. It is quite likely that none of the shrubs established from seed. We found six new shoots of *Vaccinium scoparium* on plots that had not been transplanted, but it is likely that these are root sprouts rather than seedlings. Therefore, transplanting is critical to restoration of shrub species. However, transplant survivorship was 50 percent or less for all three shrub species, *V. scoparium, Phyllodoce empetriformis*, and *Spiraea betulifolia*. Soil amendments increased survivorship for *V. scoparium*, but not the other shrubs. Amendments had no effect on shrub transplant growth or cover. Clearly, identification of treatments that can increase survivorship and growth of *V. scoparium* and *P. empetriformis* transplants is the most important research need. Transplanting at much greater densities than we used might also prove successful.

Uncommon species—None of the uncommon species planted would have established often on these campsites without planting. Of these, *Penstemon globosus* was by far the most successful. It established profusely when seeded. It survived at higher densities and grew more rapidly on plots that had been amended, although it survived at adequate densities on non amended plots. We seeded *Phleum alpinum* on three of the campsites. Large numbers of seedlings germinated and established, but most of them have eventually died. Still, in 2005, *P. alpinum* cover exceeded its target cover. Another grass, *Danthonia intermedia,* responded in a similar manner. Large numbers of seedlings established, but after 10 years, few were alive. Small quantities of the *Aster alpigenus* that established from seed were still alive in 2005, but none of the few *Sitanion hystrix* seedlings survived. By transplanting at covers that exceeded their target covers, *Aster alpigenus, Calamagrostis canadensis, Danthonia intermedia, Luzula hitchcockii, Oryzopsis exigua*, and *Polemonium pulcherrimum* all exceeded target covers after 10 years, despite low survivorship for *L. hitchcockii* and poor growth for *A. alpigenus*. *Hypericum formosum* transplants did very poor, but a few survived after 10 years. None of the transplants of *Achillea millefolium* survived. This was surprising, since *A. millefolium* is often a weedy plant.

Management Implications

A Prescription for Campsite Restoration

Our results suggest the following prescription should provide vegetative recovery of campsites in this vegetation type on a time scale of decades rather than a century or longer.

1. Effectively close the campsite to all use. Rope off the perimeter and post signs that instruct people to stay off the site and explain why.
2. Scarify soils to a depth of at least 15 cm. Break up all clods to produce a crumb texture.
3. Amend soils with at least a 2.5 cm layer of locally collected, well decomposed organic matter. Add an equivalent amount of compost. Alternatively, mix in a smaller amount of bioorganic fertilizer. For example, a

bioorganic fertilizer with 6 or 7 percent N could be applied at a rate of about 18 kg per 100 m^2.

4. Transplant *Vaccinium scoparium* and *Phyllodoce empetriformis* (if appropriate to the site) at densities at least as high as their densities on undisturbed sites. Consider growing these shrubs in nurseries, from seed collected close to the site. It also seems highly beneficial to transplant some small trees. If only a few sites are being restored, it may not be necessary to grow trees in nurseries. *Juncus parryi* is the next transplant priority. This transplanting will probably be sufficient to inoculate the soil with native biota.
5. Collect seed from a wide variety of species growing in the vicinity, preferably a year before restoration. Match the species sown to site conditions. Some species, such as *Carex rossii* and *Juncus parryi*, are appropriate on virtually all sites. Others, such as *Penstemon globosus,* may be important only on certain sites. Worthwhile species to seed include: *Antennaria alpina, Antennaria lanata, Aster alpigenus, Erigeron peregrinus, Sibbaldia procumbens,* and *Veronica cusickii*. It may be unnecessary to seed *Carex rossii* or *Juncus parryi,* if *J. parryi* is transplanted.
6. The benefits of using a mulch blanket are unclear. It is not harmful, however, and can have benefits such as keeping people off the site.
7. If possible, water plants during long, dry spells. This is most important in the first few growing seasons. However, we had transplants that had been growing well, die 4 years or more after transplanting.
8. At a minimum, inspect the closures at the start of every year to verify that ropes and signs are still up.

Restoration and Visitor Management

Restoration treatments dramatically accelerate recovery rates on closed campsites in subalpine forests. However, complete recovery will require many decades. Avoiding recreation impacts in the first place is more effective than restoring conditions after impacts occur. To promote the general principle of employing the minimally restrictive effective management technique, it has sometimes been asserted that wilderness managers should only restrict recreation (use direct management techniques) after unrestrictive (indirect) techniques are proven ineffective. When the outcome of ineffectiveness is biophysical impact, this assertion is inappropriate, particularly in ecosystems such as the subalpine forests we studied. In similar forests, Cole and Monz (2003) showed that one night of camping typically eliminated about one-half of the understory vegetation. Since impact occurs so rapidly and it takes decades for impacted vegetation to recover, wilderness managers need to proactively employ management techniques that will ensure that impacts do not exceed acceptable levels. They should not wait to prove that indirect techniques are ineffective.

As demonstrated in this study, restoration is costly in terms of effort, and particularly, time. In a wilderness such as the Eagle Cap, there may be hundreds of campsites that might be considered in need of restoration. It is not clear that we can afford to restore all these sites. To attempt substantial restoration, planning, training, and experimentation are critically important. It is not cost-effective to ask untrained wilderness rangers to do some restoration when they have time.

It is important to carefully decide which campsites to restore. At the lakes in the Eagle Cap Wilderness, it might be worthwhile to develop “hundred-year restoration plans” for each lake. One-fifth of the lakeshore could be roped off. Desired social trails, picnic sites, viewpoints, and so on, could be mapped. Impacted places not part of this infrastructure could be restored. With highly effective restoration treatments, these areas might be reopened to use in about 20 years. At that point, restoration of the next one-fifth of the lake could begin. With this approach, restoration of the entire lakeshore might be possible in 100 years. Without such planning, restoration will take much longer—if it occurs at all.

Because restoration is so costly, experimentation and monitoring are critical. It is important to identify the most effective means of restoring sites before large-scale restoration is attempted. The treatments employed in our study were not sufficient to restore the dominant shrubs in the understory. The identification of treatments that maximize survival and growth of these species remains a very high priority, particularly given the millions of hectares and thousands of campsites in western wilderness that are within this ecosystem type.

Finally, it is also critically important to ensure that restored campsites are never used again. The key here is to make it clear where people should and should not camp, and then to enforce closures. Both site manipulation and visitor management play a role in keeping people off recovering sites. As noted above, much can be accomplished by carefully planning an infrastructure of campsites and travel routes that meet the needs of visitors. At a more localized scale, large rocks can be buried in the middle of tent pads, their exposed parts making the pad unusable. Ultimately, however, it may be necessary to require visitors to use established or designated campsites and to enforce such regulations.

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