Understanding the Factors That Limit Restoration Success on a Recreation-Impacted Subalpine Site

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Abstract—Factors that limit successful revegetation of a subalpine site were studied through a combination of soil assays, greenhouse studies, and field manipulations. Campsite soils had higher available nitrogen, lower microbial community diversity, and lower seed bank density than undisturbed soils. In the greenhouse, there was no significant difference in plant growth on disturbed versus. undisturbed soils. In the field, seedling establishment patterns did not vary between experimental plots with five different soil treatments (ranging from a control to a compost and inoculum amendment). Addition of seeds and transplants increased seedling density, but not growth. Microclimatic variation may be the overriding limiting factor at this site.

Restoration of sites impacted by recreation in wilderness areas poses challenges for managers and researchers for several reasons. First, restoration of the site must be done rapidly to limit reuse, since a site that looks like a campsite, roped off or not, will likely be used for camping. Second, the goal of wilderness restoration is to revegetate with native species, and specifically, those found in the immediate area, so that revegetated patches will blend into the landscape. We have only limited information about suitable growing conditions for many native plant species, making it difficult to know what amendments will increase revegetation success. Finally, the distribution of designated wilderness areas, primarily in high-elevation and low-productivity habitats, means that wilderness restoration occurs in an environment that is itself challenging for plant establishment (Chambers 1997).

The purpose of our research has been to identify factors that limit successful revegetation of recreation-impacted sites, and to suggest ways to address those limitations. High-elevation sites, our focus for this work, are characterized by moderate to high stress conditions (a short growing season, high exposure and poorly developed soils) that can limit revegetation at all life stages. Recreation impacts produce conditions that represent an even higher stress environment for plant growth (fig. 1). Our research was motivated by reports from wilderness managers of restoration projects in high elevation environments that met with varying success, despite similar restoration protocols. We developed a hierarchical model for addressing problematic restoration projects, which takes into account limiting factors at different plant life stages, including seed availability, seed germination, seedling establishment and plant growth (fig. 2).

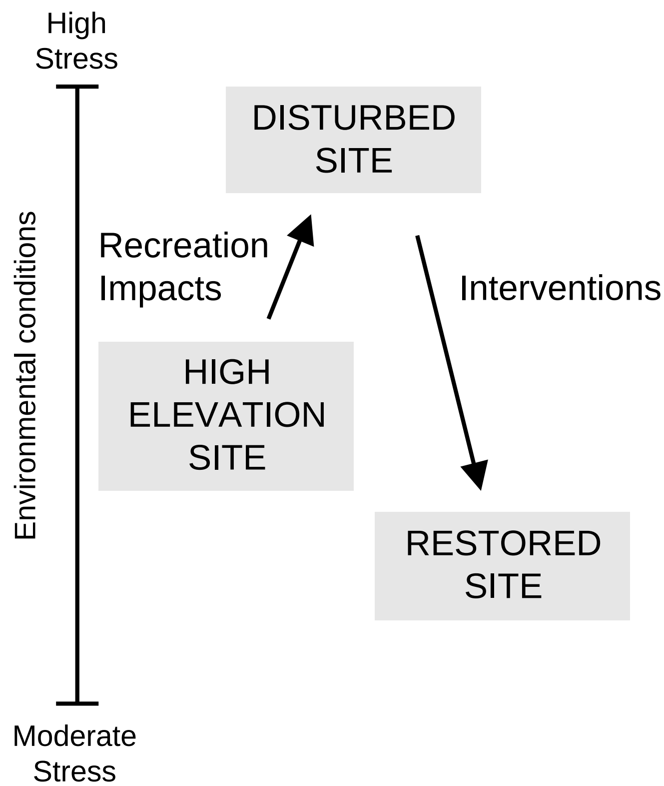

Figure 1—Stress gradient for wilderness sites impacted by recreation.

Propagule availability may be limiting in undisturbed high-elevation environments to begin with (Bliss 1971), but disturbed areas may have even fewer propagules, because of disturbance to the seed bank or from loss of parent plants that produce seeds or vegetative sprouts. Conditions for seed germination also change with recreation impacts. Changes in the soil resulting from compaction and loss of surface organic matter may limit seed germination and seedling establishment through changes in soil moisture, the availability of safe sites (Urbanska 1997), or microtopographic

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Is **propagule availability** limiting?

↓

Is **seed germination** limiting?

↓

Is **plant growth** limited by

impacted soil conditions

AND/OR

microclimatic conditions

AND/OR

biotic interactions?

Figure 2—Hierarchy for addressing factors limiting to revegetation.

conditions (Harper and others 1965). Plant growth and reproduction may be affected by environmental and soil conditions (Ebert May and others 1982, Chambers and others 1990), and by biotic interactions that have changed with the disturbance.

Our research has used a combination of greenhouse, laboratory and fieldwork to address the following hypotheses:

Question 1. How do recreation impacts affect environmental conditions that may limit plant growth?

H_1: The functional diversity of the soil microbial community does not differ in recreation-impacted sites relative to undisturbed sites.

H_2: Nutrient availability does not differ between recreation-impacted sites and undisturbed sites.

H_3: Changes in the soil due to recreation impacts do not affect plant growth under greenhouse conditions.

H_4: Seed bank density and composition does not differ between recreation-impacted sites and undisturbed sites.

Question 2. What factors limit revegetation in the field?

H_5: Propagule availability is limiting revegetation.

H_6: Germination and seedling establishment are limiting revegetation.

H_7: Establishment and growth are limited by soil conditions.

Study Site

The Heart Lake basin is a subalpine site (1,770 m elevation) in the northern Bitterroot Mountains in western Montana (46°57'N, 114°58'W). Precipitation at the site averages 208 cm annually, and the area is typically free of snow between July and October. The soils are very fine-grained and are classified as Andic Cryochrepts—Loamy Skeletal, Mixed of the Belt geological formation. Vegetation consists of scattered clumps or single trees with a dense shrub layer. Tree species present include *Abies lasiocarpa*, *Pinus contorta*, *P. albicaulis*, *P. monticola*, *Picea engelmannii* and *Tsuga mertensiana*. The understory surrounding the study sites is dominated by *Xerophyllum tenax*, *Vaccinium globulare* and *Menziesia ferruginea*.

There are four main campsites and five smaller sites on the north side of Heart Lake. In the fall of 1995, the largest of the four campsites was closed for use, and we established restoration plots on that site. The campsite is roughly rectangular, 6 m wide and 11 m long. There is one established tree within the site, and scattered clumps of *Xerophyllum tenax*.

Methods

Revegetation Study

Within the site, 25 1-m^2 plots were established, and each was randomly assigned to one of five soil treatments and one of two revegetation treatments. The soil treatments included a control, which was not treated; scarified only plots; scarified plus inoculum; scarification plus compost; and scarification plus compost and inoculum. Scarification was done by hand with pulaskis and shovels, to a depth of approximately 15 cm. Inoculum was in the form of a slurry composed of soil from an adjacent undisturbed site (c.a. 30 ml) mixed with 2 liters of stream water and incorporated into the top 15 cm of soil. Compost was added in the form of commercially available Ekocompost®. One and one-third cubic feet of compost was added to each m^2-plot and incorporated into the top 15 cm of soil.

Half of the plots were given a revegetation treatment, which included transplants and seeds. Five four-month-old *Spiraea splendens* seedlings, grown from seeds collected on site, were planted in each of the plots assigned the revegetation treatment. Seeds were collected from within one mile of Heart Lake in 1994 and 1995, and lightly raked into the surface of plots in October 1995. Species selected were common in the area and producing fruit: *Agrostis exerata*, *A. scabra*, *Achillea millefolium*, *Anaphalis margaritacea*, *Aquilegia flavescens*, *Aster occidentalis*, *Bromus caranatus*, *Carex luzulina*, *Delphinium occidentale*, *Epilobium watsonii*, *Juncus ensifolius*, *Polygonum douglasii*, *P. phytolacefolium*, *Polythicum lonchitis*, *Spiraea betulifolia*.

Soil Microbial Community Functional Diversity

Microbial community functional diversity was measured through carbon utilization profiles (Biolog®). Soil microbial communities were exposed to 95 unique carbon substrates, and their ability to metabolize the substrate was indicated by the oxidation of a tetrazolium dye. Quantification of microbial activity across this broad array of substrates is used as an indicator of the functional diversity of the soil microbial community (Seastone and others, in review). This research was summarized in a previous publication (Zabinski and Gannon 1997), and details of methodology can be found there.

Soil Nutrient Status

Fifteen cores, 2.2 cm dia x 10 cm depth, were extracted from random locations across the campsite in September 1994. An additional 15 cores were randomly located in a vegetated area adjacent to the campsite. Soil analysis was completed by Camas Analytical Labs, Inc. Total nitrogen was analyzed with the micro Kjeldahl method on a 0.5 gram sample. Phosphate-phosphorus was determined from a sodium bicarbonate extract of soil and determined by the ascorbic acid method. Iron and potassium was measured by atomic absorption spectroscopy on an ammonium acetate and DPTA extract. When data were normally distributed with equal variances, t-tests were used to test the hypothesis that nutrient levels differ on and off campsites. For non-normal data or data with unequal variances, a Mann-Whitney rank sum test was used.

Soil Effects on Plant Growth

Soil collected from Heart Lake campsites in September 1994 was used to test the effects of soil amendments and species on plant growth. The experimental design was a complete factorial with two plant species common to subalpine habitats, tufted hairgrass (*Deschampsia caespitosa*) and pearly everlasting (*Anaphalis margaritacea*); and five soil treatments—disturbed, disturbed plus compost, disturbed plus inoculum, disturbed plus compost and inoculum, and undisturbed soil. There were 10 replicates of the disturbed soil treatments and eight replicates of the undisturbed soil treatment for each species. Plants were grown for 15 weeks in 12 cm dia pots in the greenhouse, after which shoot tissue was dried and weighed. Analysis of variance was used to test for effects of soil and species and a two-way interaction on biomass accumulation. Post-hoc Tukey's tests were used for pair-wise comparisons between treatments.

Seed Bank Density and Composition

Seed bank density and composition were summarized by monitoring germinants in the greenhouse from soil samples collected from heavily impacted campsites, lightly impacted sites, and undisturbed sites. Details of methodology can be found in Zabinski and others (2000).

Factors Limiting Revegetation in the Field

Plots were monitored at two- to four-week intervals throughout the growing season during the summers of 1996 and 1997. At each sampling time, all of the plants within the m^2 plot were mapped and identified if possible. Patterns of mortality and establishment were recorded. During 1998, plots were monitored twice during the growing season, at the beginning of July and the beginning of August. At the August sampling time, height of the most common species was measured in each of the plots, and size of *Spiraea* transplants was recorded.

Results

Effects of Recreation Impacts

For four of the six soil nutrients analyzed, there were significant differences between disturbed and undisturbed sites (table 1). Both nitrate-nitrogen and ammonium- nitrogen were significantly higher on the campsite than on adjacent, undisturbed sites. Total nitrogen was lower, although not significantly, on the campsite, relative to the undisturbed site. Phosphate and potassium were significantly lower on the campsite. There was no statistical difference in iron levels between campsite and undisturbed soils.

Greenhouse Experiment

The test of plant growth on disturbed, undisturbed and amended soils showed that there were significant treatment effects for species ($F_{1,95} = 221.7$, $p < 0.001$) and soil treatments ($F_{4,95} = 33.43$, $p < 0.001$), and a significant interaction term ($F_{4,95} = 9.7$, $p < 0.001$). Pearly everlasting biomass increased with the addition of compost and inoculum, but showed no difference across the other four treatments (fig. 3). Tufted hairgrass biomass increased with the addition of compost or compost plus inoculum, and these two treatments were not statistically different from each other (fig. 4). There was no difference in growth of either species on disturbed versus undisturbed soil. The addition of inoculum by itself did not affect growth relative to the control.

Field Experiment

The number of seedlings in each plot during July 1997 did not differ between soil treatments (one-way ANOVA, $p < 0.77$; fig. 5). There was a large amount of heterogeneity within the five replicates of each treatment. In 1998, there was also no effect of soil treatment on seedling number (one-way ANOVA, $p < 0.21$; fig. 6).

Table 1—Soil nutrient analysis on and off disturbed campsite, measured as ppm.

	Campsite (n = 15)	Undisturbed site (n = 15)	Significance
NO_3-N	0.28	0.12	p = 0.011[a]
NH_4-N	9.59	3.87	p < 0.001[b]
Total N	2,813	3,325	p = 0.08 [a]
PO_4-P	12.23	24.31	p = 0.001[b]
K	136.3	188.8	p = 0.03 [b]
Fe	18.7	23.1	p = 0.26 [a]

[a]t-test with 23 df.
[b]Mann-Whitney Rank Sum Test.

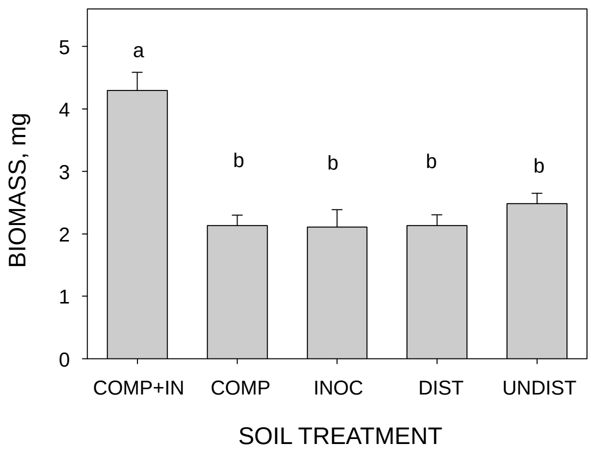

Figure 3—Pearly everlasting biomass vs. soil treatment. Treatments include disturbed soil with compost and inoculum added, compost added, inoculum added, no additions, and soil from an undisturbed site. Error bars represent standard error of the mean.

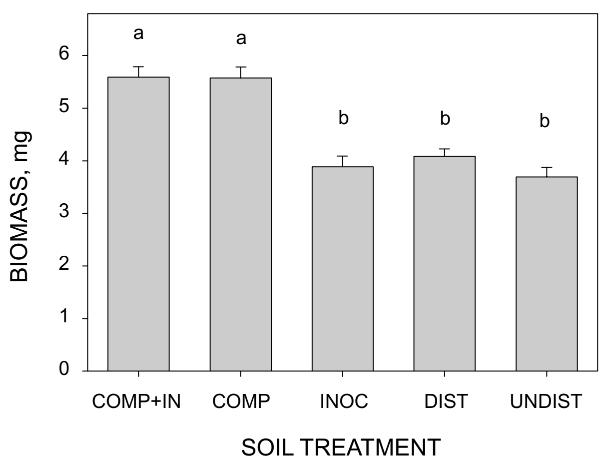

Figure 4—Tufted hairgrass biomass versus soil treatment. Error bars represent standard error of the mean.

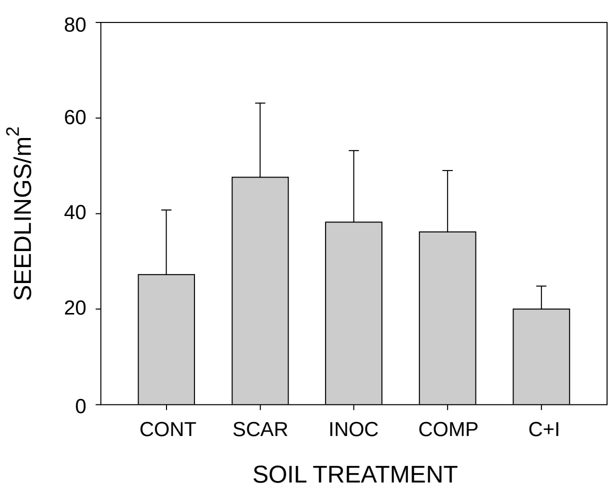

Figure 5—Number of seedlings/plot versus soil treatment, 1997 growing season. Error bars represent standard error of the mean.

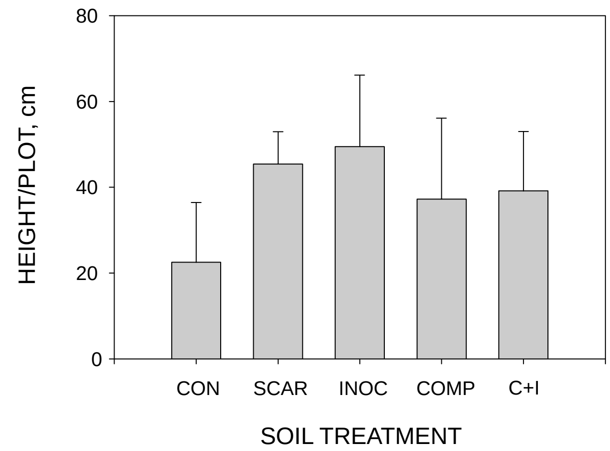

Figure 6—Number of seedlings/plot versus soil treatment, 1998 growing season. Error bars represent standard error of the mean.

In both 1997 and 1998, the number of seedlings was significantly higher with the revegetation treatment than without. In 1997, there was an average of 48 seedlings/plot on the revegetation plots, and 18 seedlings/plot on no-revegetation plots (t-test, $p < 0.005$). In 1998, differences between revegetation and no-revegetation treatments were 53 and 29 seedlings/plot, respectively (t-test, $p < 0.022$).

The average height of sedges in each plot did not differ across soil treatment (one way ANOVA, $p < 0.84$), and ranged from 2.25 cm on scarified-only plots to 2.8 cm on compost plus inoculum plots. The total height of sedges on a plot (sum of longest leaf length for each plant within the m^2 plot) did not differ between soil treatments (one-way ANOVA on ranks, $p < 0.19$; fig. 7).

Pearly everlasting was the second most common plant on the plots, occurring on 12 of the 25 plots. There were no individuals present on any of the control plots, so comparisons were made between scarified and amended plots. There was no significant soil treatment effect on total

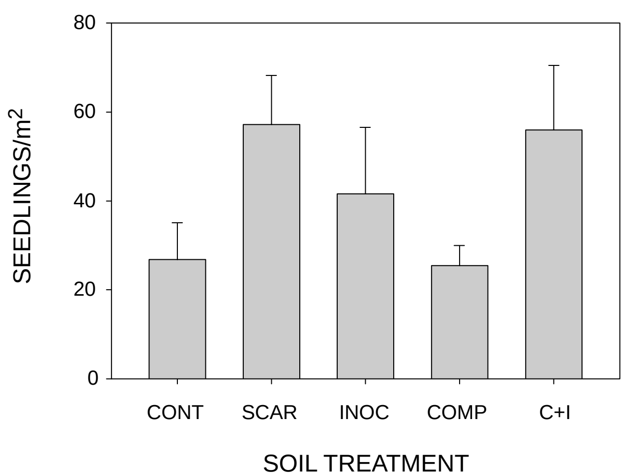

Figure 7—Total sedge height/plot versus soil treatments. Error bars represent standard error of the mean.

height (one way ANOVA, $p < 0.249$). In a comparison of the plots to which compost was added versus plots without compost (scarified only and inoculum added plots), there was a significant increase in pearly everlasting height (4.6 cm on compost treatments versus 2.5 cm on noncompost treatments; t-test, 10 df, $p < 0.046$; fig. 8). Sedge height did not differ on compost versus noncompost amended sites (t-test, 23 df, $p < 0.39$).

Scarification without soil amendments increased seedling establishment relative to controls in the Eagle Cap Wilderness (Cole and Spilbie 2000). In this study, there was a close to significant difference in the total number of seedlings on scarified relative to control plots in 1998 (t-test, 8 df, $p < 0.058$), with an average of 27 seedlings on the control plots and 57 seedlings on the scarified plots. In 1997, there was no difference in seedling number between control and scarified plots (t-test, 8 df, $p < 0.35$). There was no difference in sedge number (t-test, 8 df, $p < 0.51$) or sedge total height (t-test, 8 df, $p < 0.370$) between control and scarified plots.

Discussion

Recreation Impacts on Site Conditions

Soil conditions, including microbial community structure, nutrient availability, and seed bank density, were significantly affected by recreational use. Functional diversity of the microbial community on campsite soils was decreased by 44% relative to soils from undisturbed sites, although total numbers of microbes, as measured by colony-forming units on spread plates, were not different (Zabinski and Gannon 1997). Carbon utilization profiles are a measure of the diversity of carbon substrates that a microbial community can metabolize, and serve as a proxy measurement for soil microbial diversity. Soil microorganisms have important ecological effects on plant establishment and growth (Bever 1994, Chanway and others 1991, Turkington and others 1988), so understanding changes in the microbial community associated with disturbance and restoration amendments could be very important. But until we are able to elucidate relationships between specific microbial partners and plant species or groups, our ability to predict or ameliorate the effects of disturbance is limited.

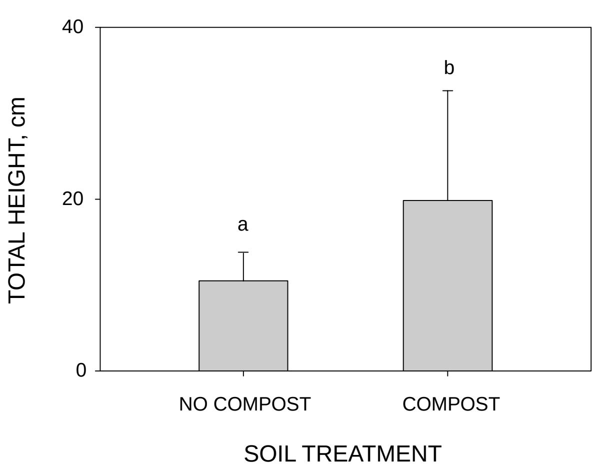

Figure 8—Total pearly everlasting height/plot versus composted/noncomposted soil treatments. Error bars represent standard error of the mean.

Available nitrogen in the form of nitrate and ammonium increased in campsite soils relative to undisturbed soils, while total nitrogen decreased. This apparent discrepancy is most likely due to a decrease in plant uptake of nitrogen on campsite soils, leaving available N, while a decrease in surface organic matter results in a less carbon-bound nitrogen. That there was no difference in plant growth in the greenhouse on disturbed versus undisturbed soils suggests that the changes in soil nutrient availability and microbial community function are not important (for at least the species tested), when plants are grown under benign conditions. The greenhouse study did not address the effect of changes in the physical structure of soil, since the process of moving soil from the field to the greenhouse disrupted patterns of compaction.

Field Revegetation Experiment

Revegetation success overall was low in this study. The number of seedlings establishing on some of the m^2 plots was over 100, but the average was 40 seedlings/m^2 during 1998. The overall growth of plants was very low. The average sedge height on a plot was near two cm, after three seasons of growth. Several species flowered on the site, including *Polygonum douglasii* and *Aster occidentalis*.

Limiting Factor: Propagule Availability

Our results suggest that propagules may be limiting natural revegetation of this site. The density and composition of the seedbank was affected by disturbance in this subalpine ecosystem. Seedbank density was 441 seeds/m^2 on heavily impacted sites, 1495 seeds/m^2 on lightly impacted sites, and 4188 seems/m^2 on undisturbed sites (Zabinski and others 2000). Ten of the 22 taxa identified from the seed bank in undisturbed and lightly impacted sites were not present on heavily impacted campsite soils (Zabinski and others 2000). This suggests that natural revegetation from seedbank soils would result in an impoverished suite of species recolonizing the site.

Field study results also suggest that propagule availability may be limiting. The only significant treatment effect in the field experiment was the revegetation treatment, which doubled the number of seedlings present. Three of the field plots that were not seeded had relatively high seedling numbers—ranging from 48 to 73 in 1998. In two of the plots, most of the seedlings are sedges, and in the third plot most of the seedlings are conifers. Both the patchy distribution of seeds and heterogeneity in conditions that affect seedling establishment could explain these results.

Limiting Factor: Seed Germination and Seedling Establishment

Limitations of seed germination and seedling establishment can be more clearly distinguished in the seeded plots within the study. Comparable amounts of seeds were added to each of the seeded plots, but numbers of seedlings on those plots ranged from 8 to 98 in 1997. On those plots with a very low number of seedlings, seed germination and seedling establishment are limiting. This may be due to biotic interactions such as herbivory, but more likely to environmental conditions. In plots with a high number of seedlings, the low growth response over the three years of this study suggesting that conditions that affect plant growth are limiting to success.

Limiting Factor: Soil Conditions

The soil treatments used in this study were designed to affect the physical, biological, and chemical properties of the campsite soils. Scarification loosens up the compacted soils, at least temporarily. The addition of compost adds large pieces of organic matter that contribute to the physical structure of the soil by providing spaces for water and root penetration. Nutrient availability also increases with compost addition, along with microbial community functional diversity. That there were no significant differences in seedling number across soil treatments suggests that soil conditions are not the primary limiting factor at this site.

Plant growth was significantly increased by the addition of compost in the greenhouse and, for pearly everlasting, in the field. This suggests that if microclimatic conditions are limiting seedling establishment on this site, and if shade cloth or water addition could ameliorate that limitation, plant growth may respond to soil treatments.

Conclusions

Revegetation at Heart Lake is limited by a combination of factors. Propagule availability is limiting across most of the campsite, as evidenced by the increase in seedling number with the addition of seed. Seed germination and seedling establishment were patchy, suggesting that environmental conditions are important in determining the success at that stage. Soil treatments showed no significant effect on seedling number or growth, suggesting that microclimatic differences that vary with patterns of sunlight and water drainage may be the primary limiting factor. This is not to suggest that soil amendments are ineffective, but that until other factors can be ameliorated, soil conditions as affected by the amendments are not limiting to revegetation success.

We will continue this work with the addition of water and a ground cover to reduce surface desiccation. On sites such as this one that are problematic for revegetation purposes, amelioration of microclimatic conditions may be essential for seedling establishment and growth.

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