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Restoration of an Alpine Disturbance: Differential Success of Species in Turf Transplants, Colorado, U.S.A.

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Abstract

Evaluating techniques for restoring alpine environments is important due to increasing human impacts on Colorado mountains. We studied restoration success after 1 yr on an alpine area disturbed by trampling at 3700 m a.s.l., Humboldt Peak, Sangre de Cristo Mountains, Colorado. This area was revegetated in summer 1997 by transplanting pieces of turf cut from a new trail. For both transplants and controls, 100 points were sampled in seventeen 70 × 70 cm plots. Vascular plant species richness did not differ between transplant and control plots. Thirty-one species showed absolute covers not significantly different between transplant and control plots, and twelve species had higher covers in control plots or showed a strong trend in that direction. Sums of covers of all species declined by 35% in transplant plots. Transplant and control plots had differential relative success of some important species as measured by relative cover although almost all differences were small. Grasses increased moderately and forbs declined by 9%. Relative cover of the dominant, *Geum rossii,* as well as two common graminoids, *Carex phaeocephala* and *Trisetum spicatum,* decreased in transplant plots. The forbs *Polygonum bistortoides* and *Potentilla subjuga* increased in relative cover in transplant plots; one of the dominant species, *Carex elynoides,* and many secondary species, were not different between treatments. Success in total cover and of almost all species after 1 yr indicates turf-transplants work well in this community and should be employed to restore other damaged alpine areas when feasible.

Introduction

Colorado mountains have seen increasing recreational demands. Attempts to climb peaks over 14,000 feet (4267 m) high increased 300% in the Collegiate Peaks, Colorado (approximately 130 km north-northwest of our study site) over the last 10 yr (U.S. Forest Service unpublished data compiled by the Colorado Fourteeners Initiative). Other Colorado peaks above 14,000 feet have likely seen similar large increases in use although quantitative data are not available. Many routes up these mountains lack constructed trails, and vegetation is trampled by thousands of people per season. Consequently, a network of unstable trails develops, often going straight up the mountain. These trails channel water runoff, which can deeply erode the trail. In order to prevent severe soil erosion, maintain intact vegetation, and preserve the aesthetics of these ecosystems, restoration of old trails and construction of new, sustainable trails is necessary. The short growing season, low seasonal increase in biomass, and unpredictable diaspore production of the alpine ecosystem (Chambers, 1995) tend to slow recovery of vegetation. Therefore, research addressing the effectiveness of various methods for restoring alpine vegetation is needed.

Extensive research has been conducted regarding revegetation and reclamation on alpine mine sites in response to legal requirements faced by mining companies (e.g., Chambers et al., 1987; Smyth, 1997). However, conditions associated with mine reclamation may not be applicable to restoration of recreational disturbances. For example, abandoned mine sites are often large areas covered by waste rock or mill tailings, which consist of crushed rock. The substrate is often acid-forming, may mobilize heavy metals, and has no organic and low nutrient content. In contrast, most trampled areas on mountain ascent routes are narrow corridors characterized by lack of vegetation and compacted, eroded soils without toxic metals or acid-forming processes. These sites are usually located in remote wilderness areas, where vehicle access is prohibited, and restoration supplies have to be carried on foot from trailheads.

Methods previously used for restoring alpine disturbances include seeding, individual tiller transplanting, and turf transplanting (Chambers, 1997; Urbanska and Chambers, in press). Seeding has been successful on relatively moderate alpine sites (Chambers, 1997). Seeding methods must consider episodic seed production (Chambers, 1989) during collection periods as well as high seedling mortality in more severe sites (Roach and Marchand, 1984 cf. Chambers et al., 1990 for higher seedling survival). On machine-graded ski runs in the Swiss Alps, direct transplanting of tillers has not been successful while indirect tiller transplants (i.e. those grown in greenhouses from harvested tillers) have worked very well (Urbanska et al., 1988; Urbanska, 1994,1997b). In Colorado, May et al. (1982) studied success of directly transplanted, entire, mature individuals of six different species in the alpine and found that root form was the most important determinant for transplant success. The plants with highest transplanting success had deep taproots, fleshy roots, well-developed secondary roots, and/or dense, fibrous roots without rhizomes. Plants that did not transplant well had shallow, fibrous roots. Marr et al. (1974) reported use of turf transplants for restoration of a linear alpine disturbance in moist sites dom-

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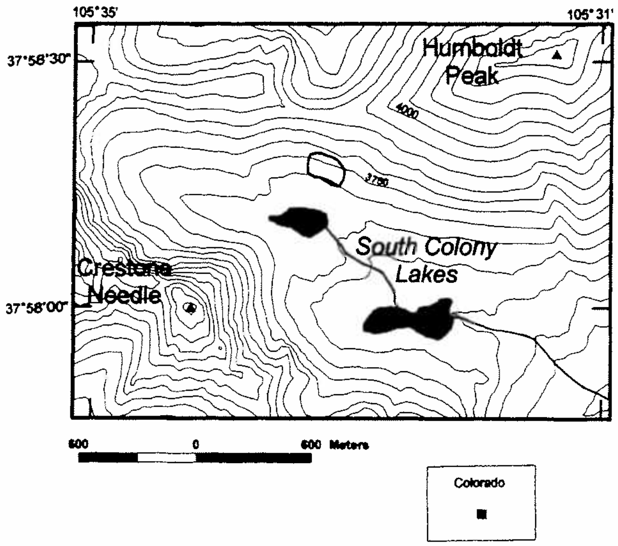

FIGURE 1. Location of the study site (heavy outline) on a steep, south-facing slope of Humboldt Peak. Contour interval 50 m.

inated by *Deschampsia cespitosa* and *Sibbaldia procumbens* in Colorado. Eighteen years later, Buckner and Marr (1988) reported high success of these transplants.

The use of turf-transplants taken from a newly cut trail may be more successful than seeding and individual transplanting due to reduced shock to individuals during the transplant process and avoidance of the susceptible germination and seedling stages (Urbanska, 1997a). Additional benefits of this method may include a more complete mix of native species, production and entrapment of diaspores, potential for vegetative expansion from the transplant into surrounding areas (Urbanska, 1994, 1997a, 1997b), and presence of an intact mycorrhizal mat. The goal of this study was to evaluate success after 1 yr of turf transplants for restoring alpine trampling disturbances within a mesic meadow.

Site Description

Research was conducted on the standard ascent route for Humboldt Peak (4290 m) in the Sangre de Cristo Mountains, Colorado (Fig. 1). Humboldt Peak lies in the Sangre de Cristo Wilderness Area in San Isabel National Forest at 37°58′N, 105°33′W. The standard ascent route climbs north from Upper South Colony Lake at 3670 m a.s.l., ascends a steep, south-facing slope of 40–50% grade to a saddle at 3920 m, and continues east along a ridge to the summit of the mountain at 4290 m. Estimates of use from trail registers are that 2000 to 3000 people travel along at least part of the trail each summer (Grobovsky, Rocky Mountain Field Institute, pers. comm., 1998).

Vegetation of the study site was a mesic alpine meadow dominated by *Geum rossii* (*Acomastylis rossii*), *Potentilla subjuga*, and *Carex elynoides*. (Botanical nomenclature is used according to the Natural Resources Conservation Service PLANTS database [USDA, NRCS 2000], with alternative names according to Weber and Wittmann [1996] in parentheses.) Slightly rockier areas had the same dominants and a larger cover of *Androsace chamaejasme*, *Minuartia obtusiloba* (*Lidia obtusiloba*), *Silene acaulis*, and *Phlox condensata*. Snowbed and drainage depressions were dominated by *Salix glauca* at low (<3720 m) elevations and by *Geum rossii*, *Potentilla subjuga*, and *Cirsium scopulorum* at higher (>3720 m) elevations. These snowbeds and wetter areas were not sampled during the study.

Precipitation and temperature data are available from the National Resources Conservation Service South Colony SNOTEL station 2.2 km southeast of the study site at the Humboldt trailhead at 3290 m a.s.l. in the forested valley bottom. Data from 1961 to 1990 show annual precipitation is 111 cm and snowpack begins to accumulate by 15 October. Snowpack reaches maximum snow water equivalent of 53 cm on 15 April and melts out in early June (Natural Resources Conservation Association, 1996). The study site has the same low soil moisture in late summer and early fall in most years (pers. obs.) that many other Rocky Mountain sites experience. This drought limits plant growth in late season (Ehleringer and Miller, 1975; Oberbauer and Billings, 1981; Enquist and Ebersole, 1994) and presumably will cause substantial water stress in newly transplanted vegetation.

Precipitation patterns in South Colony Lakes Basin for 1998 were average compared to the 30-yr mean. Total precipitation for water year 1998 (October 1997–September 1998) was 113 cm. Snowpack began to accumulate by 15 October, snow water equivalent reached its maximum of 60 cm on 15 April, and snow was gone by late May (Natural Resources Conservation Association, 1998a). Growing season (June–September) temperatures 1992 to 1998 averaged 8.4°C, with average minimums of 1.9°C and maximums of 17.3°C. The 1998 growing season was slightly warmer, averaging 9.0°C with lows of 2.5°C and highs of 18.0°C (Natural Resources Conservation Association, 1998b).

The study site is located on well-decomposed, undifferentiated arkosic sandstone, conglomeratic sandstone, siltstone, shale, and minor limestone of the Sangre de Cristo Formation (Lindsey et al., 1986). Soil pH in the top 10 cm of soil in undisturbed control sites averaged 5.95 (n = 9). On 22 August 1998, cores of the top 10 cm of soil on disturbed ground contained an average of 18.02% moisture, while control soils contained 20.33% moisture ($n = 20$, $t = 1.66$, $P = 0.12$). Nitrogen concentrations (22 August 1998) in the form of ammonia (N-NH_4^+) were not different between control plots and soil around transplants ($n = 20$, $\bar{X}_C = 0.098$ mg N g^{-1} dry soil, $\bar{X}_T = 0.095$ mg N g^{-1} dry soil, t-test, $t = 0.18$, $P = 0.86$). On the other hand, concentrations of nitrites and nitrates pooled (N-NO_2^- + N-NO_3^-) were higher around transplants ($n = 20$, $\bar{X}_C = 0.050$ mg N g^{-1} dry soil, $\bar{X}_T = 0.107$ mg N g^{-1} dry soil, t-test, $t = 2.36$, $P = 0.03$).

Methods

RESTORATION

In summer 1997, the American Mountain Foundation (AMF; now the Rocky Mountain Field Institute) closed and restored severely eroded sections of the standard ascent trail and built a new, more sustainable trail to replace it. The old trail climbed more or less directly up the slope at grades of 35 to 45% and had eroded to depths of 0.5 to 1.5 m and widths of 1.0 to 3.0 m. In order to stabilize the old trail and maximize chances of successful restoration, rock walls (0.3 to 1.0 m high) were built across the old trail. Areas behind these walls were backfilled with soil from a talus slope to create horizontal terraces between the walls.

The new trail was cut as switchbacks across the old trail in late July to early August. AMF removed pieces of tundra turf approximately 25–35 by 30–50 cm in length and width and 15 cm thick from the new trail and transplanted them onto the terraces. Most terraces received two to three turf pieces, which left substantial bare soil around the transplanted turf. The soil surface of the transplanted pieces was flush with the surrounding bare soil. Success of transplants was studied on plots located between 3700 and 3770 m a.s.l.

PLOT SELECTION AND SAMPLING PROCEDURE

In July 1998, we chose and marked control and transplant plots. Control plots were chosen to represent the composition of the transplanted turf. These plots were placed at randomly chosen intervals 1 m below the newly cut trail in the same areas from which transplants had been removed. Transplant plots were selected by identifying those terraces that had the largest transplants, which would maximize the number of data points. Based on sample size estimates from previous data collected in the Colorado alpine (Ebersole, unpublished data), we chose the 17 terraces with largest areas of transplanted turf and 17 control plots. Based on visual inspection, smaller turf blocks did not suffer higher mortality.

We used the point-intercept method for vegetation sampling according to guidelines of the International Tundra Experiment (Walker, 1996). We chose this method because it maximizes objectivity and repeatability, which is important for future monitoring of the plots. We used a 70 × 70 cm point-frame with 100 cross hairs set 7 cm apart. Repeatability of future placement of the frame was maximized by placing tags drilled with holes to fit on each of the four legs, placing two or three tags (based on availability of suitable placements) stamped with crosshairs on each plot, and leveling the four sides of the frame.

Vegetation was sampled 27 July to 2 August 1998. We collected data for absolute cover by species at each sampled plot. At each crosshair on the frame, a line was visually extended down to the vegetation, and we recorded the species hit. Where there were no plants below a point or where the plants present were from intact vegetation of the surrounding area, bare soil, rock, or intact vegetation was recorded accordingly. Multiple hits at every point were possible by moving aside the first plant structure and extending the point to the next species until every species below the point was recorded. However, multiple occurrences of the same species at a given point were not recorded. Any species present in the plot that had not been included in the sample were also noted. Because turf pieces did not occupy the full area under the frame, fewer data points were available for each transplant plot than for control plots.

COVER

Absolute cover of each species was calculated by dividing the number of hits of each species by the total number of points used for each plot. These will sum to more than 100% since more than one species can occur under one sample point. Hits on a species divided by total hits for the plot yielded relative cover. For each species, mean absolute and relative covers were compared between transplant and control plots with oneway analysis of variance (ANOVA) when parametric assumptions were met. When assumptions were not met, the Kruskal-Wallis test was used. When the null hypothesis was not rejected, power of ANOVA's was calculated according to Zar (1996). Power of the Kruskal-Wallis test was calculated as 95% of the ANOVA (Andrews, 1954).

Species were also grouped as (1) graminoids, (2) forbs, (3) Cyperaceae, and (4) Poaceae, and the groups were tested for differences in relative cover. It was not possible to test these groups for differences in absolute cover because that measurement is dependent on only one hit per group being possible at each data point.

SPECIES RICHNESS

In order to test for differences in species richness between treatments, it was necessary to correct for differences in plot size between the two groups using rarefaction (Ricklefs, 1993). We randomly selected 10 control plots and took six random samples of hits representing different size classes from each control plot (60 samples in all). The 6 size classes of 20, 30, 40, 50, 60, and 70 hits were chosen to cover the size range of transplant plots, which was 28 to 65 hits. Species richness was recorded for each of these 60 samples. An equation predicting species richness as a function of number of hits was then calculated from a linear regression. It was necessary to log-transform the number of hits to make the equation linear. This made it possible to predict species richness of each transplant plot based on its size and the assumption that richness was not different from control plots. A prediction interval (95% confidence limits for a single prediction at a given x-value) was then calculated. Differences in richness between treatments were then tested by comparing the actual richness of each transplant plot to the confidence limit of the predicted species richness from the rarefaction procedure. If the observed species richness fell outside of the confidence limits, species richness for that plot was considered significantly different from the species richness of the control plots.

Because the 95% confidence limits were broad and none of the transplant plots' richness values was significantly different from the predicted richness, a second way of testing for differences in richness between control and transplant plots was also used. The number of transplant plots with richness values above and below predictions was counted and tested for significance using the binomial distribution with the expected probability of each plot being higher or lower than predicted equal to one-half.

CHEMICAL ANALYSIS AND STATISTICAL METHODS

Soil pH, moisture content, and nitrogen content were determined using methods described in Carter (1993). All statistical tests and manipulations were performed with Minitab release 12.1.

Results

COVER

The sum of absolute covers of all species decreased 35% due to transplanting (P = 0.000, Table 1). In other words, on average there were about one-third fewer species hit at each sample point in transplanted plots than in control plots.

No species had higher absolute covers in transplant plots than in control plots (Table 1). Eight species had higher absolute cover in control plots and four more showed strong trends in this direction, but were not statistically significant ($0.05 < P \leq 0.10$). Thirty-one additional species were not different between treatments ($P > 0.10$).

Two species were found to have higher relative cover in transplant plots and eight were higher in control plots (Table 2). Additionally, two more species showed strong trends of higher cover in controls, although they were not statistically significant ($0.05 < P \leq 0.10$). Thirty-one species did not have different relative cover between treatments. Both *Polygonum bistortoides*

TABLE 1

Mean absolute cover (%) and standard error (SE) of each species (n = 17) in transplant (T) and control (C) plots

	$\bar{x}_T$	$\bar{x}_C$	SE_T	SE_C	Test	P	Power
			Species with higher absolute cover in control (C) plots				
Carex phaeocephala	1.1	6.1	0.77	2.26	K-W[a]	0.002	
Castilleja occidentalis	1.5	7.4	0.48	1.14	ANOVA	<0.001	
Geum rossii	23.9	52.0	2.57	4.44	ANOVA	<0.001	
Oreoxis alpina	0.2	2.3	0.19	0.47	K-W	<0.001	
Oreoxis bakeri	0.9	4.2	0.37	0.91	ANOVA	0.002	
Polemonium viscosum	0.2	2.5	0.15	0.42	K-W	<0.001	
Primula angustifolia	1.1	2.6	0.47	0.62	K-W	0.007	
Trifolium dasyphyllum	1.6	7.5	0.55	1.5	K-W	0.001	
			Species with no difference between treatments				
Achillea millefolium	1.2	0.1	0.85	0.06	K-W	0.255	<0.30
Allium geyeri	0.7	1.8	0.30	0.69	K-W	0.238	<0.30
Androsace chamaejasme	1.1	1.7	0.49	0.53	K-W	0.162	<0.30
Arenaria fendleri	0.0	0.4	0.00	0.31	K-W	0.151	<0.30
Artemisia scopulorum	6.3	6.4	1.58	1.63	K-W	0.986	<0.30
Carex elynoides	20.5	24.8	4.61	4.41	ANOVA	0.506	<0.30
Carex haydeniana	1.3	6.7	0.13	0.48	K-W	0.310	<0.30
Cerastium beeringianum	3.9	2.9	1.61	0.65	K-W	0.405	<0.30
Cirsium scopulorum	0.1	0.2	0.11	0.24	K-W	0.966	<0.30
Dasiphora floribunda	0.0	0.4	0.00	0.26	K-W	0.074	<0.30
Draba aurea	0.0	0.1	0.00	0.06	K-W	0.317	<0.30
Elymus trachycaulus	2.7	2.1	1.23	0.94	K-W	0.817	<0.30
Erigeron pinnatisectus	0.0	0.1	0.00	0.06	K-W	0.317	<0.30
Erigeron simplex	1.7	1.7	0.57	0.55	K-W	0.970	<0.30
Festuca brachyphylla	5.4	1.2	2.31	0.69	K-W	0.250	<0.30
Lloydia serotina	5.2	5.7	1.40	1.25	ANOVA	0.103	<0.30
Luzula spicata	0.9	0.6	0.87	0.27	K-W	0.151	<0.30
Mertensia lanceolata	0.0	0.4	0.00	0.25	K-W	0.317	<0.30
Minuartia obtusiloba	0.0	0.4	0.00	0.39	K-W	0.780	<0.30
Polygonum bistortoides	7.7	6.6	1.29	0.83	ANOVA	0.498	<0.30
Polygonum vivipara	2.7	5.8	0.91	1.73	K-W	0.130	0.33
Pedicularis parryi	0.0	0.4	0.00	0.33	K-W	0.151	<0.30
Phleum alpinum	0.7	0.0	0.68	0.00	K-W	0.317	<0.30
Poa alpina	3.8	1.3	1.85	0.73	K-W	0.494	<0.30
Poa arctica	0.2	1.3	0.16	1.09	K-W	0.310	<0.30
Potentilla subjuga	9.3	7.1	2.28	0.95	ANOVA	0.386	<0.30
Salix glauca	1.1	0.0	1.13	0.00	K-W	0.317	<0.30
Saxifraga odontoloma	0.0	0.1	0.00	0.12	K-W	0.317	<0.30
Saxifraga rhomboidea	0.5	0.1	0.29	0.07	K-W	0.255	<0.30
Silene acaulis	2.3	2.0	1.65	0.81	K-W	0.174	<0.30
Tetraneuris brandegeei	0.0	0.4	0.00	0.21	ANOVA	0.057	<0.30
Thalictrum alpinum	7.3	12.9	1.79	2.32	K-W	0.060	<0.30
Thlaspi montanum	0.0	0.1	0.00	0.07	K-W	0.317	<0.30
Trisetum spicatum	1.8	2.3	0.99	0.83	K-W	0.085	<0.30
Zigadenus elegans	0.2	0.3	0.16	0.17	K-W	0.340	<0.30
Sum of absolute covers	119.1	183.0	8.08	8.41	ANOVA	0.000	

[a] Kruskal-Wallis test

and *Potentilla subjuga* had higher relative cover in transplant plots but did not show differences in absolute cover. The eight species with higher absolute cover in control plots (Table 1) were the same eight that had higher relative cover in control plots (Table 2). *Dasiphora floribunda* (*Pentaphylloides floribunda*) and *Tetraneuris brandegeei* (*Rydbergia brandegei*) showed trends ($0.05 < P \leq 0.10$) of higher relative and absolute covers in control plots though differences between mean covers in transplant and control plots were very small. Two more species, *Thalictrum alpinum* and *Trisetum spicatum*, showed similar trends for absolute cover only.

The majority of tests for species that did not show statistical differences in cover had low power (Tables 1, 2). Many of these species had infrequent occurrences resulting in low mean cover and high standard error values, which explains the low powers of the tests. Other species were sampled frequently yet failed to show differences because sample means differed only slightly between treatments.

Mean relative cover of graminoids increased by 9 percentage points in transplant plots, while forbs decreased by the same amount (Table 2). This trend is primarily a result of an increase in relative cover in transplant plots of members of the family Poaceae, specifically *Elymus trachycaulis*, *Festuca brachyphylla*, *Phleum alpinum* (*Phleum commutatum*),

TABLE 2

Mean relative cover (%) and standard error (SE) of each species (n = 17) in transplant (T) and control (C) plots. Within rounding errors, relative covers of species add to 100% for transplant and control plots

	$\bar{x}_T$	$\bar{x}_C$	SE_T	SE_C	Test	P	Power
			Species with higher relative cover in transplant (T) plots				
Polygonum bistortoides	6.8	3.8	1.04	0.52	ANOVA	0.015	
Potentilla subjuga	7.4	4.0	1.46	0.51	ANOVA	0.039	
Poaceae	12.9	4.9	2.60	1.16	ANOVA	0.008	
			Species with higher relative cover in control (C) plots				
Carex phaeocephala	0.9	3.5	0.61	1.30	K-W[a]	0.003	
Castilleja occidentalis	1.4	4.0	0.53	0.56	ANOVA	0.002	
Geum rossii	20.3	29.7	1.89	2.70	ANOVA	0.008	
Oreoxis alpina	0.2	1.3	0.17	0.27	K-W	<0.001	
Oreoxis bakeri	0.8	2.3	0.35	0.47	K-W	0.007	
Polemonium viscosum	0.2	1.4	0.16	0.25	K-W	<0.001	
Primula angustifolia	1.0	1.5	0.44	0.33	K-W	0.037	
Trifolium dasyphyllum	1.4	4.3	0.54	0.87	K-W	0.006	
			Species with no difference between treatments				
Achillea millefolium	0.9	0.0	0.62	0.04	K-W	0.255	<0.30
Allium geyeri	0.5	0.9	0.23	0.31	K-W	0.310	<0.30
Androsace chamaejasme	0.8	0.9	0.31	0.27	K-W	0.255	<0.30
Arenaria fendleri	0.0	0.2	0.00	0.19	K-W	0.151	<0.30
Artemisia scopulorum	5.1	3.4	1.18	0.87	ANOVA	0.269	<0.30
Carex elynoides	18.4	14.7	4.09	2.97	K-W	0.546	<0.30
Carex haydeniana	0.1	0.4	0.12	0.31	K-W	0.310	<0.30
Cerastium beeringianum	3.1	1.6	1.22	0.33	K-W	0.535	<0.30
Cirsium scopulorum	0.1	0.1	0.10	0.15	K-W	0.966	<0.30
Dasiphora floribunda	0.0	0.2	0.00	0.16	K-W	0.074	0.34
Draba aurea	0.0	0.0	0.00	0.04	K-W	0.317	<0.30
Elymus trachycaulus	2.5	1.2	1.21	0.59	K-W	0.938	<0.30
Erigeron pinnatisectus	0.0	0.0	0.00	0.03	K-W	0.317	<0.30
Erigeron simplex	1.4	0.9	0.45	0.30	K-W	0.576	<0.30
Festuca brachyphylla	4.5	0.6	1.91	0.29	K-W	0.219	0.65
Lloydia serotina	4.3	3.1	1.02	0.66	ANOVA	0.353	<0.30
Luzula spicata	0.4	0.3	0.43	0.14	K-W	0.103	<0.30
Mertensia lanceolata	0.0	0.2	0.00	0.15	K-W	0.151	<0.30
Minuartia obtusiloba	0.0	0.2	0.00	0.20	K-W	0.317	<0.30
Pedicularis parryi	0.0	0.2	0.00	0.22	K-W	0.151	<0.30
Phleum alpinum	0.6	0.0	0.61	0.00	K-W	0.317	<0.30
Poa alpina	3.3	0.7	1.67	0.37	K-W	0.419	0.34
Poa arctica	0.2	0.8	0.21	0.66	K-W	0.310	<0.30
Polygonum vivipara	2.0	3.0	0.52	0.74	K-W	0.259	<0.30
Salix glauca	1.0	0.0	1.01	0.00	K-W	0.317	<0.30
Saxifraga odontoloma	0.0	0.1	0.00	0.07	K-W	0.317	<0.30
Saxifraga rhomboidea	0.5	0.0	0.28	0.03	K-W	0.255	0.44
Silene acaulis	1.9	1.0	1.19	0.40	K-W	0.297	<0.30
Tetraneuris brandegeei	0.0	0.3	0.00	0.13	ANOVA	0.067	0.59
Thalictrum alpinum	6.0	7.0	1.42	1.23	K-W	0.593	<0.30
Thlaspi montanum	0.0	0.0	0.00	0.03	K-W	0.317	<0.30
Trisetum spicatum	1.7	1.2	0.93	0.42	K-W	0.116	<0.30
Zigadenus elegans	0.2	0.2	0.21	0.11	K-W	0.340	<0.30
Cyperaceae	19.4	18.6	4.00	2.72	ANOVA	0.864	<0.30
Forbs	67.2	76.2	3.94	2.30	ANOVA	0.059	0.65
Graminoids	32.8	23.8	3.94	2.30	ANOVA	0.059	0.65

[a] Kruskal-Wallis test

and *Poa alpina*. None of these species showed significant differences individually, but did when summed into the categories graminoids and Poaceae.

SPECIES RICHNESS

We found 42 species in control plots and 33 in transplant plots. Average number of hits was 41.7 ± 2.79 ($\bar{x}$ ± SE) in transplant plots and 170.2 ± 6.40 in controls. Average species richness (not adjusted for differences in size of plots) was 12.5 ± 0.61 in transplant plots and 21.1 ± 0.77 in control plots. Species richness as a function of size of plot was described by the equation:

$$\text{Richness} = -6.89 + 12.2 \log (\text{Number of Hits}).$$

None of the observed values for richness was outside of the 95%

TABLE 3

Species richness for transplant plots showing observed values, predicted values, and the 95% confidence limits for each prediction. The difference column indicates whether the observed richness was higher (+) or lower (−) than the expected richness

Observed richness	Predicted richness	95% confidence limits	Difference
13	10.821	5.014–16.628	+
13	13.795	8.021–19.569	−
7	11.853	6.076–17.630	−
12	12.007	6.233–17.781	−
11	12.156	6.385–17.928	−
11	13.795	8.021–19.569	−
10	11.188	5.394–16.982	−
15	14.691	8.894–20.487	+
13	11.853	6.076–17.630	+
9	11.694	5.914–17.474	−
16	14.409	8.621–20.196	+
13	11.188	5.394–16.982	+
15	12.156	6.385–17.928	+
12	13.795	8.021–19.569	−
13	11.853	6.076–17.630	+
13	15.296	9.476–21.116	−
17	14.311	8.526–20.096	+

confidence limits for each prediction (Table 3). Eight plots had an observed richness higher than predicted and nine were lower. In a binomial distribution (n = 17, P = 0.5 [equal probability of observations being above or below expected]) the ratio would have to be as extreme as 13:4 for $P \leq 0.05$. Thus, species richness adjusted for size of plots is not different between transplant and control plots.

All dominant and secondary species survived in the turf transplants (Table 1). Of the 41 species in control plots, all but nine were found in turf transplants. The only species not in turf transplants were uncommon (all <0.5% cover in control plots). Two species occurred in turf transplants with low cover but not in control plots (Table 1).

Discussion

The absolute cover data are useful for examining whether individual species increase or decrease in transplant plots. It would be unusual for a species to increase in cover in the year following such a traumatic event as transplanting, so it is not surprising that no species increased in absolute cover in transplant plots. A high proportion of species (72%) did not show decreases in absolute cover 1 yr after transplanting. This indicates that most species occurring at this site survived the first year after transplanting well.

The trauma associated with transplanting probably accounts for the decrease in cover for those species that did decrease in transplant plots. *Geum rossii* is the dominant species in this alpine meadow, with over 50% absolute cover and 30% relative cover. Its decline in absolute cover from 52% in controls to 24% in transplants and in relative cover from 30% in controls to 20% in transplants clearly shows that, after 1 yr, this species does not survive turf-transplantation as well as other species. *Geum rossii* is a long-lived perennial with high root-to-shoot ratios (Chambers, 1995), and damage of its long, thick roots may have occurred when the 15-cm-thick turf-transplants were cut. Our results are markedly different from the study done by May et al. (1982) on Niwot Ridge, Colorado, which found that *G. rossii* was very successful as a transplant species when root systems of each transplant were completely excavated and transplanted. Differences between our results and those of May et al. (1982) are likely due to the transplanting technique. Thus, *G. rossii* could possibly have greater success if turf is cut more deeply. Future monitoring is important to determine how this dominant species responds in the longer term.

For *Trifolium dasyphyllum*, similar root structure to *Geum rossii* may account for the decline in its absolute and relative covers (Table 1, 2). Other species that declined significantly in absolute cover do not have similar root structures to these two species. *Castilleja occidentalis* is a hemiparasite on other plant roots, and transplanting may have disrupted these connections. *Oreoxis alpina, O. bakeri,* and *Thalictrum alpinum* are all small (<2 cm tall at this site), delicate herbs of the understory. They were likely adversely affected by handling of the turf pieces. Although there is no literature regarding the success of these species in restoration of any type, the stable soil and relatively sheltered understory environment of turf-transplants might allow survival, even at a reduced level, that would not be possible with other techniques. Reasons for the decrease in *Carex phaeocephala* are unknown.

While species may not show differences in absolute cover between treatments, relative success among species may vary as measured with relative cover. Two species increased in relative cover in transplant plots. Although the absolute covers were not different between transplant and control plots, relative cover of *Polygonum bistortoides* (*Bistorta bistortoides*) increased by 77% and *Potentilla subjuga* increased by 82%. These species were common in control plots and were among the more important species in transplant plots. Chambers et al. (1984) characterized *P. bistortoides* and *P. diversifolia,* congeneric to *P. subjuga,* as early seral dominants based on their abilities to tolerate disturbance conditions and their frequent presence as early colonizers of alpine mine disturbances in the Beartooth Mountains, Wyoming. Guillaume et al. (1986) describe *P. bistortoides* and *P. diversifolia* as having promise as native revegetation species in a study of seeding on an alpine mine disturbance in Colorado. May et al. (1982) observed high transplant success in *P. bistortoides.* These two species' abilities to colonize disturbances naturally and their success in turf-transplant revegetation may both be consequences of their adaptations to disturbance. This suggests that they will succeed in turf transplants in many locations.

Carex elynoides, one of the dominants of the undisturbed vegetation, maintained similar cover between treatments. Various species of *Carex* have been reported to do well in transplants (May et al., 1982; Urbanska, 1994) and as disturbance colonizers (Chambers et al., 1984; Rikhari et al., 1993), but other *Carex* species did not colonize disturbances at alpine mine sites in Wyoming and Montana (Chambers et al., 1984). No studies of *C. elynoides* as a restoration species have been found in the literature.

Many studies have reported the advantages of using graminoids for restoration because they are often early natural colonizers of disturbances (e.g., Guillaume et al., 1986; Chambers, 1997). In this study, graminoids had higher relative cover in transplant plots. Poaceae and Cyperaceae were tested separately, as well, though these tests of relative cover by families are not independent of each other; nor are they independent of the individual species they include. It appears that the significantly higher occurrence of members of the Poaceae is responsible for the higher relative cover of graminoids in transplant plots, while the Cyperaceae and the one species of the Juncaceae, *Luzula spicata,* show no trends at all. Thus, while all graminoid species except *Carex phaeocephala* and *Trisetum spicatum* fared well in transplant plots, members of the Poaceae were especially successful.

Both *Carex phaeocephala* and *Trisetum spicatum* were successful early seral colonizers of disturbances in the study by Chambers et al. (1984). Differences in success of these two species between the present study and Chambers et al. (1984) may have several explanations. Chambers et al. (1984) studied natural colonization, most likely from seed, as opposed to transplantation. Additionally, differences in disturbance type may account for discrepancies. All of the sites in Chambers et al. (1984) were characterized by acidic and/or metal-rich soils.

Buckner and Marr (1988) in the Front Range of Colorado found similar high success of alpine turf transplants. Their study area had high covers of *Deschampsia cespitosa* and *Sibbaldia procumbens*, indicating a moister environment with more winter snow cover than our study area. In their study, 18 yr after transplanting, species richness in five communities varied from 27 to 36 in control plots. Sampling an area twice as large for turf transplants as for controls, they found a mean in the five communities of 4.0 species found in the control plots but not in turf transplants and 3.2 species in transplants but not controls (calculated from Tables in Buckner and Marr, 1988). All species not in both transplant and control plots had very low cover (Buckner and Marr, 1988). Our results indicate success of turf transplants is also possible in less moist environments with less winter snow cover.

Overall success of turf transplants in this study was high. While relative cover of forbs declined in transplant plots, the decline of just 9% points was modest, and forbs still dominated after 1 yr. Despite lower overall plant cover in transplant plots, survival of all growth forms, survival of all dominant and secondary species, and maintenance of a rich assortment of species shows transplanting turf is very successful at rehabilitating such a disturbance. Because transplants were studied just 1 yr after transplantation, long-term monitoring of these plots is needed to thoroughly evaluate the turf-transplant technique. Additionally, studies addressing possible vegetative expansion and diaspore production, distribution, and entrapment within transplants will increase our understanding of alpine restoration and success of the turf-transplant technique.

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