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Success of Turf Transplants in Restoring Alpine Trails, Colorado, U.S.A.

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Abstract

Heavy, increasing recreation on Colorado's high peaks has created numerous social trails requiring restoration. We studied success of turf transplants 3 yr after transplanting on Mount Belford in the Sawatch Range, and Humboldt Peak in the Sangre de Cristo Range. Based on point-intercept data, sum of all vascular species' covers was 12% to 31% lower in transplanted plots than in control areas. We found no differences in canopy density and height between transplant and control plots on Mount Belford, while both were about 40% lower in transplants on Humboldt Peak. Species richness adjusted for plot size was slightly greater in transplant plots on Mount Belford and slightly lower on Humboldt Peak. On both peaks, we found greater absolute cover of grasses in transplant plots, while forb cover was lower. After 3 yr, turf transplants effectively established vegetation cover and maintained high species richness in these communities. Whenever turf is available, e.g., new trail construction, it should be used to restore closed social trails and campsites, and turf transplants can be considered in other ecosystems for small disturbances in high-value areas where restoration would otherwise be slow.

Introduction

Alpine areas from the Austrian Alps (Grabherr, 1982) to Australia (Buckley et al., 2000) to the northeastern United States (Ketchledge, 1991) have experienced increasing recreational use and subsequent trampling damage to vegetation for the past several decades. In the Rocky Mountains, recreational use damaged alpine areas in heavily visited national parks several decades ago (Willard and Marr, 1970). Although the alpine zone of the Rocky Mountains faces threats due to anthropogenic nitrogen deposition (Baron et al., 2000), increasing UV-B radiation, and climate change, recreational degradation provides the largest threat to ecosystem integrity in terms of loss of vegetation and animal habitat (Bowman et al., 2002).

Increased use and trampling damage occur especially on Colorado's "Fourteeners" (peaks $\geq$14,000 ft = 4268 m). On each of four Fourteeners in the Sawatch Range, people signing summit registers increased from several hundred in 1982 to 750–2000 by 1992. Median increase on these four peaks over the 10-yr period was 10% yr^{-1} (U.S. Forest Service unpublished data). Similar increases are clearly occurring on other Fourteeners, which have limited use data.

In the past decade several groups began constructing sustainable trails to summits of these peaks and stabilizing and restoring eroded social trails (Hesse, 2000). Since natural seedling establishment is usually slow in the alpine (Chambers et al., 1990) and since recolonization even of very small bare areas is limited in dry communities after 30 yr (Ebersole, 2002), active restoration is required.

Restoring alpine vegetation is often difficult due to the limited number of species available as colonizers, short cool growing seasons, episodic seedling establishment, and unpredictable diaspore production (Chambers, 1997). Additionally, in Colorado, most high peaks are 3 to 9 km (2 to 5 mi) from roads and in federally established Wilderness Areas, which adds further logistical, financial, and physical limitations.

Seeding of native species proved successful at high elevations in some situations (Bayfield, 1980; Guillaume et al., 1986; Chambers, 1997). However, seeds and seedlings are more susceptible to environmental hazards (Urbanska, 1997a), so seeding can take longer to revegetate areas than transplanting. Indirect single species transplants, in which whole plants are removed, split into single rootstocks, and propagated in a greenhouse before transplanting were successful on ski runs in Switzerland. However, directly transplanting these plant parts without rooting in the greenhouse was not successful (Urbanska et al., 1987; Urbanska, 1994). Transplanting large turf pieces may be appropriate when turf is available from trail construction. Benefits of turf transplants include reduced shock to individuals, greater mix of transplanted species, immediate diaspore production, potential safe sites for seedlings, and vegetative expansion (Urbanska, 1997a, 1997b, 1997c).

In this study, we evaluated success of turf transplants on steep slopes well above treeline 3 yr after transplanting into closed social trails on two Colorado Fourteeners. If successful, turf transplants obtained from trail construction or other activities may serve as an important tool in restoring alpine communities, and perhaps vegetation in other ecosystems. We evaluated success in terms of: (1) establishing vegetation cover, (2) maintaining relative cover of growth forms, (3) retaining the high species richness of undisturbed sites, (4) retaining canopy height and density, (5) survival of individual species, and (6) effects of transplanting on flowering.

Site Description

Both study sites are within National Forest Wilderness Areas, and all studies were done on social trails that were closed after construction of new trails.

Mount Belford is located in the Sawatch Range at 38°58′N, 106°21′W. The study site was located between 3660 and 3720 m (12,000 to 12,200 ft) on a steep (15° to 35°), northwest-facing, broad ridge crest. Grasses, sedges, and *Geum rossii* dominate the vegetation [botanical nomenclature follows the Natural Resource Conservation Service PLANTS database (2001)]. Bedrock is gneiss, and the soils are gravelly sandy. An estimated 4000 to 5000 people hiked some or the entire trail in 1999 (Desrosiers, Colorado Fourteeners Initiative, personal communication, 1999).

In 1996, the American Mountain Foundation (AMF, now the Rocky Mountain Field Institute) closed the old, eroded trail that went straight up the northwest ridge, and cut a new trail with switchbacks. As they cut blocks of tundra turf from the new trail (no smaller than 20 × 30 cm and 10 cm thick, they immediately placed them into the

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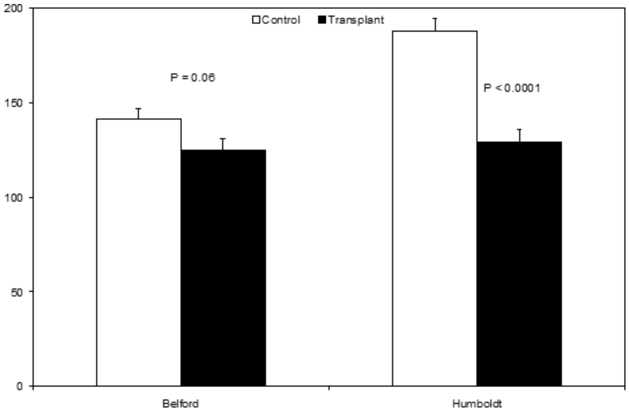

FIGURE 1. Sum of absolute covers of vascular plants (mean + SE) after 3 yr in control and transplant plots on Mount Belford ($n = 10$) and Humboldt Peak ($n = 17$).

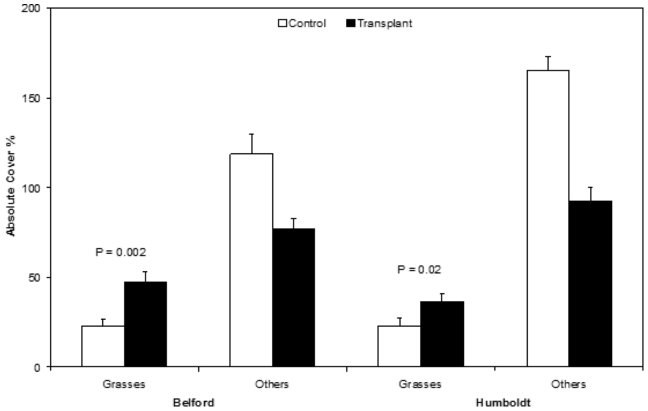

FIGURE 2. Sum of absolute covers of grasses and all other growth forms combined (mean + SE) in control and transplant plots on Mount Belford ($n = 10$) and Humboldt Peak ($n = 17$).

old trail and packed soil and rocks around them to stabilize them and to discourage hikers from using the old trail. Turf blocks were placed with very little bare ground between them.

The Humboldt Peak study site is in the Sangre de Cristo Mountains at 37°58′N, 105°33′W. The study site for the turf transplant experiment lies between 3700 and 3770 m (12,100 to 12,400 ft) on a steep (20° to 30°), south-facing slope. Surrounding vegetation is mesic alpine meadow dominated by *Geum rossii* and *Carex elynoides*. Other common species included *Polygonum bistortoides* and *Potentilla subjuga*. Soils are derived primarily from conglomeratic sandstone. In 1996 an estimated 3500–3600 people climbed Humboldt Peak (M. Smith, U.S. Forest Service, personal communication, 1999).

In 1997 on Humboldt Peak, AMF closed and restored the social trail that climbed directly up the steep fall line on the south-facing slope that leads to a saddle at 3900 m (Hesse, 2000). Channeled water and hikers had severely eroded steeper sections of this trail into a gully 0.5 to 1.5 m deep and 1 to 3 m wide. Rock walls (0.3 to 1 m high) were built across the gully to stabilize it. These terraces were backfilled with rock from nearby talus slopes and topped with raw soil from under talus. As on Mount Belford, AMF removed pieces of tundra turf as the new trail was cut (approximately 25–35 × 35–50 cm in length and width and 15 cm thick) and immediately transplanted them onto the terraced areas of the closed social trail. Volunteers dug turf blocks into centers of terraces, and turf generally covered 50% to 90% of the bare area.

Methods

On each peak, we did point-intercept sampling in late July to early August 3 yr after transplanting. On Humboldt Peak we measured the same transplant and control plots (17 of each) studied by Conlin and Ebersole (2001) 1 yr after transplanting. On Mount Belford we chose 10 transplant plots that had less than 25% cover of rocks and bare ground. Ten control plots were located at randomly selected places 0.5 m uphill of the backslope of the newly cut trail. Control plots were 70 × 70 cm, and transplant plots were 4200 to 4900 cm^2 depending on the size and arrangement of turf blocks. We saw no evidence of trampling on control plots on either peak because steep backslopes of the trail and steep overall slope make it very difficult to walk there.

We used a 70 × 70 cm point-frame, with a double set of 100 cross hairs set 7 cm apart to sample vegetation, rock, and bare ground. We potentially recorded multiple hits at each point by moving aside the first plant structure and extending the visual line to the next structure(s) below. We used these data to measure canopy density (number of hits/point). To measure canopy height we recorded height of the first plant structure hit at every fourth point.

We determined absolute cover (percentage of points in the plot that were not rock) for each species in each plot. On Mount Belford no differentiation was made between bare ground within turf blocks and bare ground around turf blocks during sampling. We assumed there would be same percentage of bare ground within the transplanted turf blocks as in the control plots (7.8% ± 1.2%) and used this to correct the total number of points in the plot (vegetation plus bare ground). We used rarefaction (Ricklefs, 1993) to correct for differences in plot size between transplant and control plots (see Conlin and Ebersole, 2001, for details).

We measured flowering on Mount Belford by counting inflorescences by species in the total plot area, and we calculated inflorescence densities by dividing number of inflorescences by the total points in the plot. We compared parameters between transplant and control plots with one-way ANOVA or Kruskal-Wallis test when parametric assumptions were not met.

Results

Transplanted plots had less vegetation cover than control plots on both peaks (Fig. 1). On Mount Belford total cover was 17 percentage points or 12% lower than the 142% cover in control plots ($P = 0.056$). However, on Humboldt Peak it was 59 percentage points or 31% lower than the 188% cover in control plots ($P < 0.001$). On both peaks, absolute cover of grasses was greater in transplanted plots than in control plots, and forb cover was greater in control plots (Fig. 2). On Humboldt Peak, cover of grasses was 14 percentage points greater in transplants; however, sedge species cover was 14 percentage points lower.

On Mount Belford, 38 of 49 species and 36 of 52 species on Humboldt Peak seem to have tolerated transplanting well and did not show a difference in absolute cover ($P > 0.05$; Table 1; covers by species are in Appendix 1). Much of the difference in absolute cover after 3 yr can be attributed to only a few species. Specifically, both *Geum rossii* and *Carex elynoides*, two of the most common species, had substantially lower cover in transplant plots. However, most of the species showing significantly less cover in transplant plots on both peaks had only small differences (<5% points). All of the forbs with greater cover in transplant plots are small, short-lived species. Yet, the common grass *Poa alpina* did have greater cover in transplant plots on Humboldt Peak as well.

Canopy height on Mount Belford ranged from 0 cm to 32 cm within transplant plots and 0 cm to 29 cm within control plots, and it was not different between the two groups (Fig. 3). On Humboldt Peak canopy height ranged from 0 cm to 36 cm within transplant plots and

TABLE 1

Number of species by growth form with greater absolute cover ($P \leq 0.05$) in transplant and control plots and species not significantly different in cover between treatments on Mount Belford and Humboldt Peak, Colorado.

	Transplant	Control	No difference	Total
Mount Belford	6	3	40	49
Forbs	3	3	31	37
Graminoids	3	0	9	12
Cyperaceae	0	0	4	4
Poaceae	3	0	4	7
Humboldt Peak	2	14	36	52
Forbs	1	11	27	39
Graminoids	1	3	9	13
Cyperaceae	0	3	2	5
Poaceae	1	0	6	7

0 cm to 25 cm within control plots; mean canopy height in transplant plots was 47% lower than in control plots ($P \leq 0.001$; Fig. 3). We also found that canopy density was 38% lower in transplants on Humboldt Peak ($P \leq 0.001$; Fig. 4). Canopy density on Mount Belford did not change significantly (Fig. 4).

Total inflorescences per point on Mount Belford were 45% higher in transplant plots ($P = 0.049$; Appendix 2 shows inflorescence density by species). Flowering doubled in transplant plots in Poaceae ($P = 0.009$) and was nearly eliminated in Cyperaceae ($P = 0.002$). Flowering in forbs was not significantly different between transplant and control plots.

Seven species showed a higher inflorescence density in transplant plots than controls, and seven species showed greater number of inflorescences in control plots (Table 2, Appendix 2). Thirty other species showed no differences among treatments ($P > 0.05$). Four of six species with higher absolute cover in transplant plots also had a greater inflorescence density. Species with statistically higher inflorescence densities in transplant plots and also with more than small absolute differences compared to control plots were short-lived forbs (*Cerastium beeringianum*, *Draba breweri*), grasses, (*Poa alpina*, *Trisetum spicatum*), and *Luzula spicata* (Appendix 2). The two community dominants, *Geum rossii* and *Carex elynoides*, as well as *Trifolium nanum*, had substantially lower inflorescence density in transplant plots (Appendix 2).

After correction for differences in plot size, species richness was greater in transplant plots than in control plots on Mount Belford. On Humboldt Peak species richness was slightly less in transplant plots than in control plots (Fig. 5).

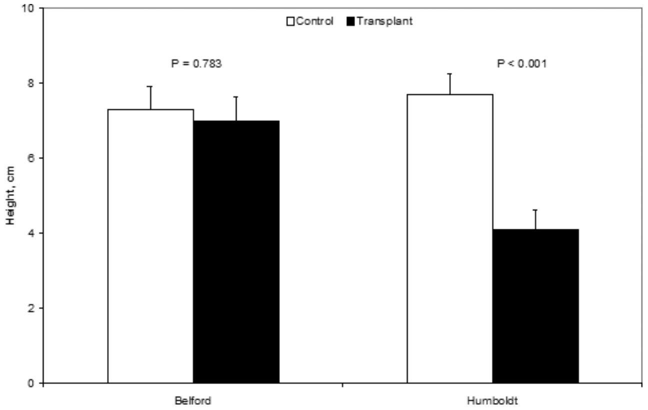

FIGURE 3. Vegetation height (mean + SE) in transplant and control plots on Mount Belford and Humboldt Peak.

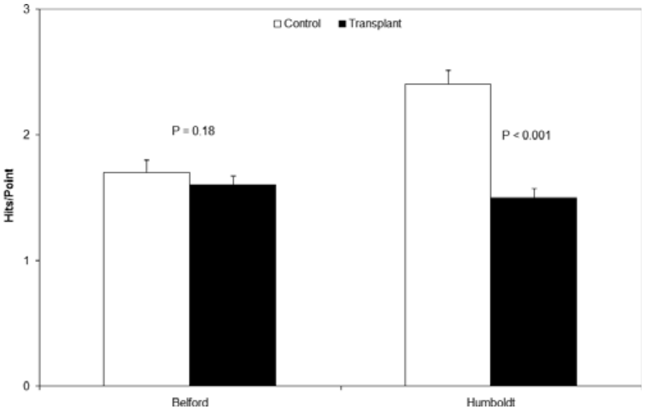

FIGURE 4. Canopy density (mean + SE) in transplant and control plots on Mount Belford and Humboldt Peak.

Discussion

On both Mount Belford and Humboldt Peak turf transplants survived well for 3 yr and maintained good cover (though less than control areas) and the high species richness of the surrounding vegetation. The better success (less reduction in total cover, fewer species not decreasing in cover, higher species richness relative to control, and less reduction in canopy height) on Mount Belford than on Humboldt Peak is likely explained by more favorable soils and moisture regime. The south-facing Humboldt Peak site presumably has drier soils than the northwest-facing Mount Belford site. The Sangre de Cristo Mountains (Humboldt Peak) also apparently receive less snow and melt out earlier than the Collegiate Peaks (Mount Belford). While both study sites have similarly coarse soils, soils around turf blocks on Mount Belford had twice as much organic carbon (4.12 ± 0.83 g C g^{-1} dry soil vs. 1.95 ± 0.59 on Humboldt Peak) and about 20 times as much extractable nitrogen (4.0 vs. 0.2 mg N g^{-1} dry soil).

While most species tolerated transplanting well, several important species did not. *Geum rossii* and *Polemonium viscosum* showed significantly lower absolute cover in transplant plots at both sites and also in the study by Buckner and Marr (1988). These two species account for most of the decline in forb cover. However, while *G. rossii* cover decreased in transplants from 1998 to 2000 on Humboldt Peak, *P. viscosum* cover actually increased slightly. Conlin and Ebersole (2001) attributed the decrease in *G. rossii* cover to tap root damage when the turf was cut, because May et al. (1982) had success with *G. rossii* when the roots were excavated individually. *G. rossii* is one of the most common alpine plants in several alpine communities, and it occurs in several others. To retain it in substantial amounts as part of restored vegetation, deeper turf blocks, individual transplants, or other techniques may be necessary.

The significantly higher relative cover of Poaceae in transplant plots supports the conclusions of Buckner and Marr (1988) and

TABLE 2

Number of species by growth form with greater number of inflorescences ($P \leq 0.05$) in transplant and control plots and species without significant differences in inflorescence density between treatments on Mount Belford, Colorado.

	Inflorescences per point			
	Transplant	Control	No difference	Total
Mount Belford	7	7	33	47
Forbs	4	5	27	36
Graminoids	3	2	6	11
Cyperaceae	0	2	1	3
Poaceae	2	0	5	7

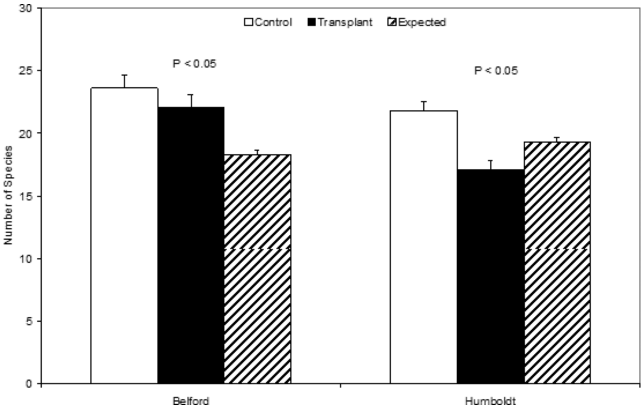

FIGURE 5. Species richness (mean + SE) in control and transplant plots on Mount Belford ($n = 10$) and Humboldt Peak ($n = 17$). Statistical tests compare actual transplant values with richness expected for plots of that size if transplanting did not affect richness.

Urbanska et al. (1987) that grasses do well when transplanted in the alpine. While graminoids in general have been found to be highly successful in transplants (e.g., Guillaume et al., 1986), we found lower absolute cover of Cyperaceae in transplant plots on both Humboldt Peak and Mount Belford.

The success of alpine turf transplants we observed is consistent with results of Buckner and Marr (1988). They examined success of turf 18 yr after transplanting during pipeline burial in the Colorado Front Range. They found that although the site had not completely recovered to pre-disturbance conditions, no visually noticeable difference remained between the transplants and the surrounding vegetation. In the drier and earlier melting communities on Mount Belford and Humboldt Peak 3 yr after transplanting, more differences exist between transplant and control plots, but nevertheless turf transplants can be very successful in these drier alpine plant communities commonly disturbed on Colorado's high peaks. Whenever turf is available, e.g., from new trail construction, it should be used to restore closed social trails and other small disturbances such as campsites. Turf transplants may also work effectively to restore small disturbances in other ecosystems in high-values areas where restoration would otherwise be slow.

Acknowledgments

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References Cited

Baron, J., Rueth, H., Wolfe, A., Nydick, K., Allstott, E., Minear, J., and Moraska, B., 2000: Ecosystem responses to nitrogen deposition in the Colorado Front Range. *Ecosystems,* 3: 352–368.

Bayfield, N., 1980: Replacement of vegetation on disturbed ground near ski lifts in the Cairngorm Mountains, Scotland. *Journal of Biogeography,* 7: 249–260.

Bowman, W., Cairns, D., Baron, J., and Seastedt, T., 2002: Islands in the sky: tundra and treeline. *In* Baron, J., Fagre, D., and Hauer, R. (eds.), *Rocky Mountain futures: an ecological perspective.* Washington, D.C.: Island Press, 183–202.

Buckley, R., Pickering, C., and Warnken, J., 2000: Environmental management for alpine tourism and resorts in Australia. *In* Godde, P., Price, M., and Zimmermann, F. (eds.), *Tourism and development in mountain regions.* New York: CABI Publishing, 27–45.

Buckner, D., and Marr, J., 1988: Alpine revegetation of Rollins Pass after 18 years. *In* Keammerer, W., and Brown, L. (eds.), *Proceeding: High Altitude Revegetation Workshop no. 8.* Fort Collins: Colorado Water Resources Research Institute, Colorado State University, Information Series no. 59, 273–290.

Chambers, J., 1997: Restoring alpine ecosystems in the western United States: environmental constraints, disturbance characteristics, and restoration success. *In* Urbanska, K., Webb, N., and Edwards, P. (eds.), *Restoration ecology and sustainable development.* Cambridge: Cambridge University Press, 161–187.

Chambers, J., MacMahon, J., and Brown, R., 1990: Alpine seedling establishment: the influence of disturbance type. *Ecology,* 71: 1323–1341.

Conlin, D. and Ebersole, J., 2001: Restoration of an alpine disturbance: differential success of species in turf-transplants. *Arctic, Antarctic, and Alpine Research,* 33: 340–347.

Ebersole, J., 2002: Recovery of alpine vegetation on small, denuded plots, Niwot Ridge, Colorado, U.S.A. *Arctic, Antarctic, and Alpine Research,* 34: 389–397.

Grabherr, G., 1982: The impact of trampling by tourists on a high altitudinal grassland in the Tyrolean Alps, Austria. *Vegetatio,* 43: 209–217.

Guillaume, M., Berg, W., and Herron, J., 1986: Performance of native and introduced species seven years after seeding on alpine disturbances. *In* Shuster, M., and Zuck, R. (eds.), *Proceedings: High Altitude Revegetation Workshop no. 7.* Fort Collins: Colorado Water Resources Research Institute, Colorado State University, Information Series No. 58, 131–141.

Hesse, M., 2000: Mount Humboldt climbing route improvement and restoration project: a case study in addressing recreational impacts on Colorado's wilderness peaks. *In* Keammerer, W. (ed.), *Proceedings: High Altitude Revegetation Workshop No. 14.* Fort Collins: Colorado Water Resources Research Institute, Colorado State University, Information Series No. 91, 64–69.

Ketchledge, E., 1991: Vegetation restoration in northeastern alpine zones. *In* Decker, D., Krasny, M., Goff, G., Smith, C., and Gross, D. (eds.), *Challenges in the conservation of biological resources: a practitioner's guide.* Boulder, Colorado: Westview Press, 317–329.

May, D., Webber, P., and May, T., 1982: Success of transplanted alpine plants on Niwot Ridge, Colorado. *In* Halfpenny, J. (eds.), *Ecological Studies in the Colorado Alpine.* Boulder, Colorado: Institute of Arctic and Alpine Research, Occasional Paper No. 37, 73–81.

Natural Resource Conservation Service, 2001: The PLANTS Database, Version 3.1 (http://plants.usda.gov), U.S. Department of Agriculture. National Plant Data Center, Baton Rouge, LA 70874-4490, U.S.A.

Ricklefs, R., 1993: *The Economy of Nature.* Third edition. New York: W. H. Freeman, 576 pp.

Urbanska, K., 1994: Ecological restoration above the timberline: demographic monitoring of whole trial plots in the Swiss Alps. *Botanica Helvetica,* 104: 141–156.

Urbanska, K., 1997a: Restoration ecology of alpine and arctic areas: are the classical concepts of niche and succession directly applicable? *Opera Botanica,* 132: 189–200.

Urbanska, K., 1997b: Restoration ecology research above the timberline: colonization of safety islands on a machine graded alpine ski run. *Biodiversity and Conservation,* 6: 1655–1570.

Urbanska, K., 1997c: Safe sites—interface of plant population ecology and restoration ecology. *In* Urbanska, K., Webb, N., and Edwards, P. (eds.), *Restoration Ecology and Sustainable Development.* Cambridge: Cambridge University Press, 81–110.

Urbanska, K., Hefti-Holenstein, B., and Elmer, G., 1987: Performance of some alpine grasses in single tiller cloning experiments and in the subsequent revegetation trials above timberline. *Berichte des Geobotanischen Institutes ETH Stiftung Rubel,* 53: 64–90.

Willard, B. and Marr, J., 1970: Effects of human activities on alpine tundra ecosystems in Rocky Mountain National Park, Colorado. *Biological Conservation,* 2: 257–265.

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APPENDIX 1

Absolute covers (%, mean ± 1 S.E.) of species and growth forms in transplant (T) and control (C) plots on Mount Belford and Humboldt Peak, Colorado. Species listed are those with $\geq$3% mean cover in any of the four groups and/or those with significant differences. Greater means ($P \leq 0.05$ from 2-tailed Kruskal-Wallis tests) are noted with C or T. Blanks indicate the species did not occur on that peak.

	Mount Belford			Humboldt Peak		
	mean$_{\mathrm{T}}$ ± 1 S.E.	mean$_{\mathrm{C}}$ ± 1 S.E.	*P*	mean$_{\mathrm{T}}$ ± 1 S.E.	mean$_{\mathrm{C}}$ ± 1 .S.E.	*P*
Androsace chamaejasme				0.53 ± 0.31	2.69 ± 0.69	0.003 C
Androsace septentrionalis	1.49 ± 0.38	0.21 ± 0.14	0.008 T	0.10 ± 0.10	0.00 ± 0.00	0.317
Artemisia scopulorum	11.12 ± 3.17	16.31 ± 3.04	0.289	2.22 ± 0.62	4.99 ± 1.17	0.082
Besseya alpina	0.00 ± 0.00	0.80 ± 0.39	0.030 C			
Calamagrostis purpurascens	5.89 ± 2.89	9.22 ± 2.09	0.112			
Carex elynoides	4.77 ± 1.18	14.46 ± 5.53	0.112	9.18 ± 2.20	19.88 ± 4.37	0.039 C
Carex rupestris	7.68 ± 3.22	12.62 ± 4.49	0.322	0.00 ± 0.00	0.07 ± 0.07	0.317
Carex scopulorum				0.00 ± 0.00	1.65 ± 0.79	0.004 C
Carex sp.				0.06 ± 0.06	2.66 ± 1.82	0.034 C
Castilleja occidentalis	0.00 ± 0.00	0.60 ± 0.34	0.068	0.40 ± 0.18	4.79 ± 0.70	0.000 C
Cerastium beeringianum	13.47 ± 3.54	6.34 ± 1.87	0.241	3.80 ± 1.12	3.73 ± 0.75	0.591
Draba breweri	3.30 ± 0.85	0.71 ± 0.16	0.002 T			
Elymus trachycaulus				6.31 ± 2.71	6.93 ± 2.29	0.645
Erigeron simplex	0.38 ± 0.38	0.30 ± 0.30	0.942	1.29 ± 0.75	1.94 ± 0.43	0.042 C
Festuca brachyphylla	4.28 ± 0.51	0.83 ± 0.37	0.024 T	9.15 ± 2.51	5.23 ± 1.53	0.231
Geum rossii	3.28 ± 1.76	17.09 ± 4.63	0.008 C	17.13 ± 2.65	52.33 ± 4.66	0.000 C
Lloydia serotina	2.56 ± 1.01	1.03 ± 0.44	0.267	2.07 ± 0.63	6.23 ± 1.43	0.005 C
Luzula spicata	3.46 ± 0.75	1.41 ± 0.52	0.055	2.16 ± 0.81	1.32 ± 0.46	0.955
Mertensia lanceolata	0.35 ± 0.23	3.36 ± 1.55	0.110	0.22 ± 0.12	1.93 ± 0.62	0.012 C
Oreoxis bakeri				1.04 ± 0.36	5.02 ± 0.92	0.001 C
Packera wernerifolia				1.03 ± 0.54	0.00 ± 0.00	0.036 T
Poa alpina	12.58 ± 5.22	3.50 ± 3.50	0.003 T	5.44 ± 1.82	0.68 ± 0.29	0.039 T
Poa arctica	16.13 ± 3.42	6.11 ± 0.90	0.016 T	2.64 ± 0.81	2.48 ± 1.12	0.211
Poa glauca subsp. *rupicola*	4.26 ± 1.21	1.52 ± 0.46	0.078			
Polemonium viscosum	1.74 ± 0.97	8.03 ± 2.46	0.009 C	0.53 ± 0.27	3.58 ± 0.70	0.000 C
Polygonum bistortoides				11.47 ± 1.77	9.58 ± 1.17	0.352
Potentilla hookeriana	2.00 ± 0.99	3.04 ± 1.02	0.428			
Potentilla subjuga				14.03 ± 2.29	8.62 ± 1.50	0.102
Ranunculus pedatifidus	1.83 ± 0.61	0.20 ± 0.14	0.027 T			
Silene acaulis	0.62 ± 0.26	3.31 ± 2.29	0.733	4.48 ± 2.68	1.23 ± 0.55	0.357
Tetraneuris brandegeei				0.62 ± 0.62	1.18 ± 0.47	0.028 C
Thalictrum alpinum	0.92 ± 0.54	5.72 ± 3.45	0.675	6.70 ± 1.55	14.08 ± 2.56	0.025 C
Trifolium dasyphyllum	0.00 ± 0.00	1.04 ± 0.93	0.147	2.17 ± 0.98	4.11 ± 1.38	0.247
Trifolium nanum	5.20 ± 1.90	8.71 ± 1.76	0.139	0.65 ± 0.31	3.66 ± 2.02	0.054
Trifolium parryi				0.10 ± 0.10	1.24 ± 0.64	0.038 C
Trisetum spicatum	4.04 ± 1.29	1.53 ± 0.51	0.109	11.13 ± 2.79	6.98 ± 1.31	0.605
Forbs	59.84 ± 4.20	88.28 ± 9.13	0.005 C	79.84 ± 7.42	138.90 ± 7.07	0.000 C
Graminoids	64.43 ± 5.92	53.11 ± 6.23	0.174	49.41 ± 3.94	48.99 ± 3.94	0.823
Cyperaceae	13.37 ± 4.27	28.99 ± 5.96	0.059	10.60 ± 2.23	24.78 ± 4.22	0.007 C
Poaceae	47.61 ± 5.53	22.71 ± 4.23	0.007 T	36.65 ± 3.95	22.89 ± 4.73	0.011 T
Total	124.60 ± 6.37	141.60 ± 5.36	0.069	129.25 ± 6.45	187.89 ± 6.32	0.000 C

APPENDIX 2

Inflorescences per point (mean ± 1 S.E.) of species and growth forms in transplant (T) and control (C) plots on Mount Belford, Colorado. Species listed are those with ≥0.05 inflorescences per point in either group and/or those with significant differences. Greater means ($P \leq 0.05$, Kruskal-Wallis test) are noted with C or T.

	Inflorescences per point		
	mean_T ± S.E.	mean_C ± S.E.	*P*
Androsace septentrionalis	0.14 ± 0.04	0.02 ± 0.01	0.010 T
Artemisia scopulorum	0.16 ± 0.07	0.07 ± 0.02	0.344
Calamagrostis purpurascens	0.15 ± 0.08	0.04 ± 0.03	0.425
Campanula uniflora	0.00 ± 0.00	0.03 ± 0.02	0.031 C
Carex albonigra	0.00 ± 0.00	0.02 ± 0.01	0.013 C
Carex elynoides	0.02 ± 0.01	0.48 ± 0.21	0.002 C
Carex rupestris	0.00 ± 0.00	0.08 ± 0.05	0.068
Castilleja occidentalis	0.00 ± 0.00	0.03 ± 0.01	0.005 C
Cerastium beeringianum	0.96 ± 0.37	0.16 ± 0.06	0.044 T
Draba breweri	0.17 ± 0.05	0.02 ± 0.01	0.013 T
Festuca brachyphylla	0.09 ± 0.04	0.04 ± 0.02	0.434
Geum rossii	0.01 ± 0.01	0.14 ± 0.04	0.002 C
Luzula spicata	0.11 ± 0.04	0.03 ± 0.02	0.042 T
Poa alpina	0.42 ± 0.19	0.16 ± 0.16	0.005 T
Poa arctica	1.06 ± 0.35	0.60 ± 0.11	0.762
Poa glauca subsp. *rupicola*	0.14 ± 0.07	0.06 ± 0.02	0.751
Potentilla hookeriana	0.01 ± 0.01	0.05 ± 0.02	0.031 C
Ranunculus pedatifidus	0.05 ± 0.02	0.00 ± 0.00	0.014 T
Silene acaulis	0.00 ± 0.00	0.28 ± 0.16	0.091
Trifolium nanum	0.00 ± 0.00	0.13 ± 0.07	0.005 C
Trisetum spicatum	0.08 ± 0.03	0.01 ± 0.00	0.012 T
Forbs	1.72 ± 0.34	1.10 ± 0.21	0.198
Graminoids	2.08 ± 0.37	1.50 ± 0.23	0.226
Cyperaceae	0.02 ± 0.01	0.58 ± 0.20	0.002 C
Poaceae	1.94 ± 0.34	0.90 ± 0.16	0.009 T
Total	3.79 ± 0.03	2.61 ± 0.14	0.049 T