1996

Restoring alpine tundra following road disturbances on Bald Mountain, Wyoming| An ecological approach to species selection

Todd R. Caplan
The University of Montana

RESTORING ALPINE TUNDRA
FOLLOWING ROAD DISTURBANCES
ON BALD MOUNTAIN, WYOMING:
AN ECOLOGICAL APPROACH TO SPECIES SELECTION

by:

Todd R. Caplan

B.A. Roanoke College, 1987

presented in partial fulfillment of the requirements

for the degree of

Master of Science

The University of Montana

1996

Approved by:

[signature]

Chairperson

[signature]

Dean, Graduate School

6-24-96

Date

ACKNOWLEDGMENTS

I would like to give thanks to my parents John and Marsha Ramsay for their unyielding support and for teaching me to pursue my life passions; to my partner Kristin Soeder for her love, patience, and encouragement; and to my friends and family who help me laugh at myself when I get too serious.

I also wish to extend thanks to my good friend Mark Vander Meer for invaluable field assistance; to Anna Marshall for her help editing this paper; to Greg Bevenger, Kent Houston, and Phyllis Rosebury of the Shoshone National Forest for their kindness and support; and to my graduate committee members, Drs. Donald Bedunah, Ragan Callaway, and Paul Alaback of the University of Montana, and Dr. Ray Brown of the U.S.D.A. Forest Sciences Laboratory, for providing invaluable guidance and encouragement.

Financial support for this project was provided by the Shoshone National Forest.

Caplan, Todd R., M.S., May 1996 Forestry

Restoring Alpine Tundra Following Road Disturbances on Bald Mountain, Wyoming: An Ecological Approach to Species Selection (56 pp.)

Director: Donald J. Bedunah

Revegetating alpine areas following human related disturbances requires careful selection of locally adapted alpine plant species. Species selection should be based upon ecological information including colonization ability and species distribution patterns. Factors which influence these patterns should also be investigated, such as edaphic limitations and plant reproductive traits. I investigated these ecological attributes in order to compile a list of revegetation candidate species for reclaiming roads in the alpine zone of Bald Mountain, Wyoming.

Plant cover and soil characteristics were recorded along 32 road transects and 26 tundra transects. Plant cover was lowest on roads of the south aspect. Species composition in both roads and tundra differed according to aspect. Many species occurred only on specific aspects while other species were ubiquitous. Species differences were also found in various road "treatments" (cut slope, road center, fill slope). While not directly measured, probable factors influencing plant distribution patterns on road and tundra include: water availability, seed dispersal, seed dormancy, seed bank, and plant competition. Candidate species for revegetating road disturbances were listed by aspect and treatment and are based upon results from the vegetation data.

Hydrothermally altered soil supported the lowest plant cover on the study site: probably due to aluminum toxicity associated with acid soil (pH< 4) exposed following road construction. Soil amendments must accompany appropriate species selection if revegetation of this substrate is attempted.

Five disturbance colonizers *(Agoseris glauca, Oxytropis lagopus, Phacelia sericea, Lupinus argenteus,* and *Solidago multiradiata)* were studied for their seed germination requirements. Only seed of *Lupinus argenteus* and *Solidago multiradiata* responded to germination treatments. *L. argenteus* germinated readily following cold/wet treatment (81%) alone while *S. multiradiata* seed germinated mostly after dark growth chamber conditions (64%). Seed of *Agoseris glauca, Oxytropis lagopus,* and *Phacelia sericea* were viable, but dormant. Germination requirements of several revegetation candidates not investigated in this study were found in the literature.

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INTRODUCTION

The restoration of native plant communities following human related disturbance is becoming increasingly important as scientists and land managers recognize the numerous functions these communities perform. Diverse native plant communities provide important wildlife habitat, maintain functional hydrologic regimes, and perpetuate themselves through stochastic environmental events. Land reclamation, however, often involves seeding disturbed landscapes with commercially available plant species which fail to perform these broad ecological functions. These commercially available species are commonly not native to the disturbed ecosystem and often times are Eurasian weed species. Many revegetation projects, especially those in extreme climates, fail because the commercially available plants are poorly adapted to the site conditions. This is particularly true in high elevation alpine ecosystems.

Environmental conditions of alpine ecosystems are inherently harsh. Plants of non-equatorial alpine regions have a narrow window of opportunity (45-90 days) each year to acquire enough nutrients to promote stem elongation, develop flowers, and reproduce (Bliss 1985). In an environment where cold soil temperatures (8-13°C) limit microbial activity (Haselwandter et al 1983, Schinner 1982) and mineralization rates (Haselwandter et al. 1983, Marion & Miller 1982), these tasks are especially difficult. Dramatic daily temperature oscillations (10-12°C) at high elevations (Bliss 1985) also contribute to the harsh alpine climate. These diurnal fluctuations promote soil freeze/thaw action and provide an unstable soil environment that limits plant colonization (Johnson & Billings 1962). Plant establishment and growth are further hindered by high windspeeds common to alpine ecosystems. High speed winds limit water availability on windward slopes by drying soil and redistributing snow to leeward slopes (Billings & Mooney 1968). Deep and late-melting snowdrifts on lee slopes further reduce the time plants need to fulfill their annual life requirements. Such site conditions render alpine revegetation efforts particularly challenging and indicate why plant species used to reclaim lower elevation sites may not establish and survive here.

Alpine natives have evolved numerous adaptations enabling them to grow, reproduce and survive in this harsh environment. Plants adapted to alpine environments concentrate their above-ground and below-ground biomass near the soil surface where microclimates are most favorable (Billings 1974). Annuals are rare; most alpine plants are perennial herbs having relatively large underground root and/or rhizome systems for storing carbohydrates and nutrients through winter (Billings 1974, Körner 1989, Mullen & Schmidt 1993). Over-winter storage provides an immediate energy and nutrient source following snowmelt to initiate life processes for the short growing season (Billings & Mooney 1968). Körner (1989) found that alpine plants maintain relatively high tissue concentrations of nutrients compared to lower elevation species, suggesting high nutrient use efficiency among alpine species.

Using locally adapted native plants to revegetate high-elevation disturbances is important not only because they can survive the rigors of alpine ecosystems, but because they have evolved complex relationships amongst themselves (Carlsson & Callaghan 1991), with soil biota (Allen et al. 1987, Haselwandter & Read 1980, Trappe 1988), and with insect and mammal species (Galen & Stanton 1989, Huntly 1987, Mattson et al. 1991). It is well documented that introduced (not locally native) plant and animal species can interfere with these complex interactions and reduce biological diversity (Bobbink & Willems 1987, Coblentz 1978, Hobbs & Huenneke 1992, Soulé 1990, Vitousek et al 1987). Biological diversity improves community stability and increases resistance to disturbance events (Tilman 1996). A primary goal in restoration ecology is to "jump-start" the recovery of these complex interactions and re-instate biological diversity lost following human related disturbances. Although re-creating plant communities disturbed or destroyed by such activities may be difficult, at best, we can reintroduce members of the pre-disturbance plant community as a means of initiating recovery. Ecological knowledge is essential to achieving this goal. Knowledge of plant succession and plant reproductive ecology is especially useful because this information can be applied to selecting plant species best suited to revegetating disturbed areas.

Understanding how species colonize disturbances may help identify revegetation candidates. For example, although vegetative dispersal through rhizomes is known to be the dominant form of regeneration in tundra environments (Bliss 1971), under favorable conditions many alpine perennials produce large quantities of viable seed (Amen 1966, Bliss 1971, Sayers & Ward 1966). In fact, natural colonization of xeric disturbed sites may be exclusively dependent upon seed rain (Cargill & Chapin 1987). Although the total seed rain onto xeric sites may be large, dispersal of species able to survive on the sites may be limited. Brown et al. (1976) found that only about 10% of the native vascular species on the Beartooth Plateau are active, natural colonizers on alpine disturbances.

Disturbance colonizers are often components of mature tundra communities that show distinctive "weedy" tendencies following disturbance (Marchand & Roach 1980). Restoration projects which apply knowledge of such reproductive characteristics to guide species selection may increase the potential for success. Identifying and sowing or planting native species with weedy tendencies may greatly speed recovery (Cargill & Chapin 1987).

Information on germination requirements may also be used to facilitate revegetation efforts. Investigating seed dormancy and germination requirements of species having revegetation potential is useful for determining appropriate seed pre-treatments (e.g. scarification or stratification) and methods of planting (Chambers et al. 1987). Recent investigations have focused specifically on alpine species with revegetation potential (Acharya 1989, Chambers 1989, Chambers et al. 1987, Clebsch & Billings, 1976; Haggas et al., 1987; Hermesh & Acharya, 1990, and Urbanska & Schutz 1986). However, compared with lower elevation species, the germination requirements of alpine species have received relatively little attention worldwide (Acharya 1989). As mining and other ecologically destructive activities above treeline continue, further research on germination requirements of alpine revegetation candidates is especially important.

Combining autecological research with investigations of alpine plant communities and disturbance colonization is a more holistic approach to restoring plant communities to disturbed sites. This approach is enhanced by investigating edaphic effects on community composition and disturbance colonization. For example, acid drainage limits species colonization and commonly occurs following high elevation mining activities (Brown et al. 1984). Less commonly, soils derived from hydrothermally altered parent material may support completely different plant communities than adjacent unaltered soils (Billings, 1950; Schlesinger et al.,1989; and Salisbury, 1964). Failing to recognize such edaphic controls may limit the success of plant restoration efforts.

I have used this holistic approach to species selection for revegetating a high-elevation road network in the southern Absaroka Range, Wyoming. This approach included the following: identifying important natural road colonizers relative to their significance in the "undisturbed" tundra community; investigating germination requirements of selected species and; identifying species proportionally more common on hydrothermally altered soils. My purpose was three-fold: 1) identify alpine plants best suited for revegetating abandoned roads above treeline on Bald Mountain, 2) describe factors which influence alpine plant species distribution on Bald Mountain, and 3) provide a framework for future investigations of species selection for revegetating abandoned roads in harsh climates.

Following a study site description, this paper is organized into four main sections. In Section 1, I present the methods and results of plant sampling in roads and tundra of Bald Mountain. Revegetation candidates are presented here. Section 2 includes methods and results related to the soil investigation. Section 3 describes my methods and results from the seed germination experiments. Finally, Section 4 comprises a synthesis of the previous sections including hypotheses of mechanisms which influence alpine plant distributions and its applicability to revegetating road disturbances.

STUDY AREA

The study site is the alpine zone of Bald Mountain, located between T. 45 & 46 N, and R. 103 & 104 W., in northwest Wyoming. It is situated at the head of the Wood River drainage approximately 25 km southwest of the town of Meeteetsee. Temperature information collected since 1990 at the base of Bald Mountain indicates mean monthly low and high temperatures from June through September ranged from -3.7°C to 25°C. Mean monthly precipitation for the same time period was 59.2 cm. (Taylor 1996).

Bald Mountain is at the southern end of the Absaroka Range- the only range in northwestern Wyoming of volcanic origin. The alpine zone of Bald Mountain begins at roughly 3000 meter elevation and comprises an area of approximately 1.6 km^2. Bald Mountain's gentle 3161 meter "summit" is more like a bench leading to the north ridge of 3614 m Spar Mountain. Below the alpine tundra, Bald Mountain supports subalpine forests dominated by *Picea engelmannii* and *Abies lasiocarpa* to the north and west while Spar Creek flows below the steeper east aspect.

Rocks underlying the Bald Mountain area are assigned to the Wiggins Formation of Oligocene (and possibly late Eocene) age (Wilson 1964). This formation forms a series of deuterically propylitized hornblende-biotite and pyroxene andesite porphyry flows, tuffs, breccias, and volcaniclastic sediments (Hausel 1982). A rough oval-shaped zone of intense hydrothermal alteration occurs on the northwest flank of Bald Mountain and is associated with a volcanic vent complex with exposures of intrusive rhyolitic tuff breccia (Wilson 1964). Major alteration products include sericite, mixed-layer illite-montmorillonite, quartz, and biotite with lesser kaolinite and chlorite. Major sulfides include chalcopyrite, molybdenite, and pyrite. The alteration processes resulted in mineralized zones occupied by copper, molybdenum, and traces of gold (Hausel 1982).

Mineralization of this area was first discovered in the 1880's and small mining claims were established quickly thereafter. Mining activity increased near the turn of the century, and soon a town of 200 people existed at the base of Bald Mountain. The town (Kirwin) was buried by an avalanche in 1907. Little mining activity followed, and for at least the next 50 years, the area was used primarily as rangeland for domestic sheep grazing (Bevenger 1995). In the early 1960's, the American Metals Climax Corporation (AMAX) bought the land to explore the mineral potential of Bald Mountain. An extensive road network was established throughout the mountain for exploratory drilling between 1963 and 1965. Total road length above treeline is estimated to be 3.5 to 5.5 km. These roads were used heavily until 1974 when AMAX ceased exploratory operations. No large scale mining ever occurred. In the fall of 1985, AMAX reportedly seeded all "unused" roads with a non-native seed mixture of 50% smooth brome (*Bromus inermis*) and 50% intermediate wheatgrass (*Agropyron intermedium*) or with a mixture of 30% *B. inermis*, 30% orchard grass (*Dactylis glomerata*), 15% timothy (*Phleum sp.*) and 25% white Dutch clover (*Trifolium sp.*) (Smith 1995). Reclamation efforts were unsuccessful and the Shoshone National Forest, which now manages the area, is considering revegetating the roads using alpine natives.

SECTION I. VEGETATION

FIELD METHODS

Roads and tundra of the Bald Mountain alpine zone were examined for plant colonization and community composition, respectively, from July 12 to August 15, 1995. The study site was stratified by aspect and, because total road length and tundra area differed in each aspect, transect numbers varied accordingly. Voucher specimens from road and tundra sampling locations were collected, identified, and verified at the University of Montana herbarium. Nomenclature follows Hitchcock & Cronquist (1973).

Vegetation Sampling on Roads. Thirty-two randomly located road sampling sites (north-10, south-7, east-5, west-10) were established above treeline. At each sample site, a transect was established in the road center and followed the road length for 15 meters. Parallel transects were established along the adjacent cut and fill slopes rendering three sampling "treatments" (cut, road center, fill) per site. There were ninety-six transects total.

Along each transect, $0.25m^2$ plot frames were placed two abreast at five-meter intervals (8 plot frames per transect/treatment). Exceptionally wide cut and fill slopes were sampled using twice the number of plot frames per transect. A species area curve was developed to determine these plot numbers. Individual plants observed within a plot frame were identified and species canopy cover was recorded according to cover class midpoints (Table 1). In addition to plant cover, percent cover of rock (> 75mm diameter), gravel (2-75mm diameter), soil (< 2mm diameter), moss, and organic matter (dead plant tissue) were recorded. Site characteristics including slope angle, aspect, and elevation were also recorded.

Vegetation Sampling in Tundra. "Islands" of tundra were spatially separated by the matrix of roads. Although tundra islands were subjectively chosen for sampling, transect locations within each island were randomly established. In total, twenty-six (26) tundra transects were established (north-10, south-6, east-3, west-7). Species canopy cover was recorded using a 0.25m² plot frame spaced every two meters along a 24m transect (totaling 12 plots per transect). A species area curve was developed to determine this plot number. Canopy cover values were recorded according to cover class midpoints (Table 1). Additionally, canopy cover of soil, gravel, rock, moss, and organic matter were recorded at each transect as were slope angle, aspect, and elevation.

Table 1. Eleven cover classes.

Range	Midpoint
1 - 5%	2.5%
5.1 - 15%	10%
15.1 - 25%	20%
25.1 - 35%	30%
35.1 - 45%	40%
45.1 - 55%	50%
55.1 - 65%	60%
65.1 - 75%	70%
75.1 - 85%	80%
85.1 - 95%	90%
95.1 - 100%	97.5%

ANALYSIS

Roads. Plot data collected along a transect was averaged so that each transect represented one sample. Mean cover was calculated for individual plant species and relative frequency of a species was calculated by counting the number of plots in which it was found and dividing that number by the total number of plots per transect. Relative cover and relative frequency were summed to obtain "importance values" (IV's) for individual species from each transect.

Summary statistics were calculated by combining IV data for all species occurring in treatments of similar aspects. Boxplots were developed to graphically display how the data was distributed. Species with IV's above the 75th percentile were considered successful road colonizers and were listed as revegetation candidates. The IV corresponding to the 75th percentile differed for each aspect and were as follows: north- 20, south- 7, east- 20, and west- 10. Species having IV's below these subjectively chosen cut-off levels were not placed on a list of revegetation candidates.

From the list of revegetation candidates, mean species IV's were compared between road and tundra transects at each aspect. Road IV's were obtained by collapsing IV's from all three treatments (cut, road center, fill). Species having IV's greater in the road than the tundra remained on the revegetation list. For species with IV's greater in the tundra than the road, Levene tests for equality of variance and independent samples t-tests were run to determine significant (Levene test: $p < 0.10$; t-test: $p < 0.05$) differences in mean IV (SPSS; Norusis 1993). Species with significantly greater IV's in the tundra were considered "unsuccessful" road colonizers and were dropped from the revegetation list. "Candidate" species with revegetation potential were compiled for each aspect.

Tundra. Plot data collected along a transect was averaged so that each transect represented one sample. Mean cover was calculated for individual plant species and relative frequency of a species was calculated by counting the number of plots in which it was found and dividing that number by the total number of plots per transect. Relative cover and relative frequency were summed to obtain "importance values" (IV's) for individual species from each transect. Importance Values (IV's) were calculated for plant species recorded along each tundra transect.

Alpine plant community types were grouped through multivariate analysis of the vegetation data using classification and ordination programs (PC-ORD, McCune 1993). Plants were classified using Two-Way Indicator Species Analysis (TWINSPAN) and indirectly ordinated using Detrended Correspondence Analysis (DCA). TWINSPAN is a divisive hierarchial classification program using reciprocal averaging repeatedly to divide the data set into smaller and smaller groups (Hill 1979). Indicator species identifying community types are selected after weighing all transect data.

DCA is an eigenvector ordination technique which ordinates simultaneously both the species and the sites by a re-iterative weighting procedure (Hill 1979). DCA displays floristic gradients between stands along its axes. The program extracts factors from the raw data matrix which explain most of the variation in co-occurring species. Equal distances in the ordination should broadly correspond to equal differences in species composition (Hill 1979, Hill & Gauch 1980). Site and species ordinations correspond precisely; therefore, it is possible to make direct interpretations of the site ordination in terms of species composition (Whittaker 1987). This program was used to re-examine community types indicated by TWINSPAN.

RESULTS

Roads. Percent plant cover on roaded areas of Bald Mountain on south (mean 34.2 ± s.e. 9.5) west (mean 45.3 ± s.e. 6.2), east (mean 60.0 ± s.e. 11.8), and north aspects (mean 63.5 ± s.e. 9.0) were not significantly different ($p > .05$)
(Figure 1).

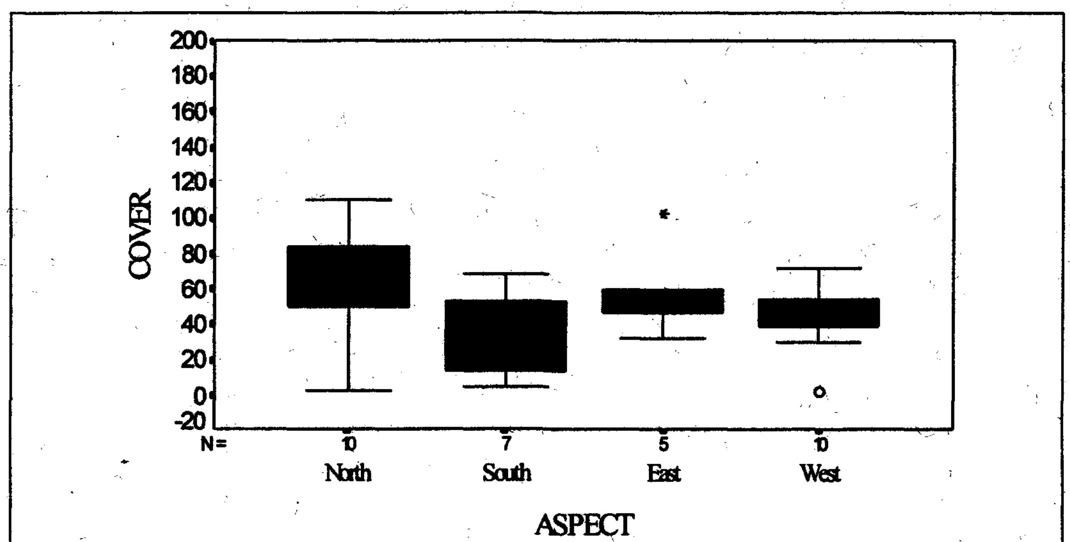

Figure 1. Boxplots of percent plant cover by aspect. 50% of all cases have values in the box. Median values are indicated by dark lines within the boxes. The lower boundary of the box is the 25th percentile and the upper boundary is the 75th percentile. Whiskers represent the largest and smallest observed values that are not outliers. Asterisk indicates extreme outliers.

Although mean percent cover on fill slopes 79.1 ± 7.4) was nearly twice those of cut slopes (36.9 ± s.e. 4.2) and road centers (38.5 ± s.e. 3.9), these differences were not significant ($p > .05$) (Figure 2).

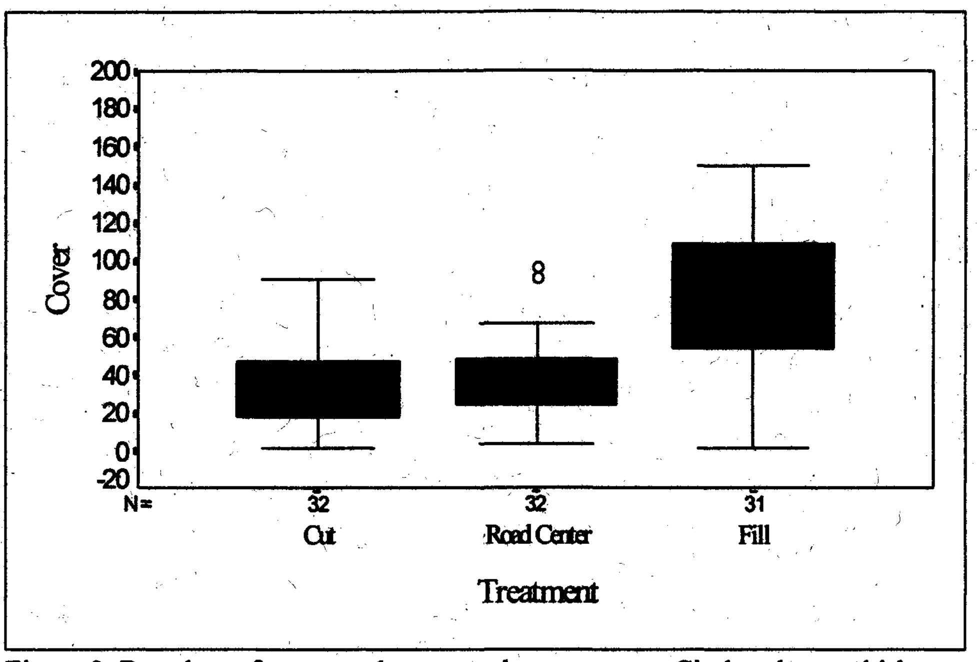

Figure 2. Boxplots of percent plant cover by treatment. Circles above whiskers of the road center boxplot represent outliers.

Factors associated with wind exposure (water availability, airborne soil and ice particles) and slope angle (erosion, snow avalanches) may account for the high variability in plant cover observed between transects. Roads having the highest plant cover were usually located in fill slopes on leeward aspects with slopes < 5°. Lowest cover values were generally located on steeper (30°-45°), wind exposed, south/west aspects. Exceptions were three sampling locations with total plant cover < 5%. In these isolated cases, soil pH (<4.0) may have influenced vegetation cover more than slope aspect (Table 2).

Table 2. Site characteristics of road transect with lowest and highest vegetation cover.

	Cover	pH	Aspect	Elevation	Slope	Treatment	Transect #
1	1.2	3.6	West	10,200'	25°	Fill	16
2	1.2	3.8	North	10,250'	35°	Cut	17
3	3.1	4.7	South	10,500'	2°	Cut	8
4	3.7	3.6	West	10,200'	25°	Center	16
5	3.7	3.7	West	10,200'	25°	Cut	16
6	4.4	3.7	North	10,250'	35°	Center	17
7	4.4	3.8	South	10,500'	2°	Center	8
8	7.2	5	South	10,250'	40°	Center	5
9	8.1	3.9	South	10,500'	2°	Fill	8
10	8.3	4.9	South	10,450'	38°	Cut	7
86	105.9	4.9	South	9950'	20°	Fill	3
87	106.2	4.5	East	10,450'	7°	Fill	22
88	112.5	4.9	West	10,350'	3°	Fill	27
89	113.4	4.8	South	9900'	20°	Fill	2
90	113.7	4.5	North	10,425'	3°	Fill	28
91	117.5	4.5	East	10,475'	5°	Fill	26
92	118.7	4.4	North	10,325'	2°	Fill	20
93	130	4.2	North	10,200'	1°	Fill	30
94	130.9	4.8	East	10,375'	2°	Fill	24
95	150	5.1	North	10,200'	3°	Fill	19
96	150	4.7	North	10,425'	3°	Fill	21

A list of revegetation candidates was devised from the transect data following IV cut-off levels (Table 3). This list was scaled down after IV comparisons between road and tundra transects were made (Table 4).

Table 3. Species with importance values above aspect cutoff levels.*

	Aspect			
Grass/sedge spp.	North	South	East	West
Agropyron caninum	X	X	X	X
Agropyron scriberni		X		X
Carex atrata	X		X	
Carex phaeocephala			X	
Deschampsia cespitosa		X		
Festuca idahoensis	X		X	X
Leucopoa kingii				X
Poa alpina	X			
Poa secunda	X	X	X	X
Trisetum spicatum	X		X	X
Erect Forb spp.				
Agoseris glauca	X	X	X	X
Artemesia michauxiana		X		X
Erigeron compositus				X
Geum rossii			X	
Lupinus argenteus	X		X	
Myosotis alpestris	X			X
Oxytropis lagopus				X
Penstemon whippleanus				X
Phacelia alpina		X		X
Phacelia sericea		X		X
Polygonum bistortoides	X		X	
Potentilla diversifolia	X		X	X
Senecio canus		X		
Solidago multiradiata	X	X	X	X
Spreading Forb spp.				
Achillea millefolium	X	X	X	X
Antennaria umbrinella		X		X
Artemesia scopulorum	X			
Astragalus alpinus	X	X		X
Cerastium beeringianum	X	X	X	X
Phlox pulvinata		X		X
Sedum lanceolatum		X	X	X

* Importance value cut-off levels are north-20, south-7, east-20 and west-10

Table 4. Importance value comparisons between road and tundra.

Species	Aspect	Importance Value (mean ± s.e.) Road	Tundra	Significance‡
Grass/Sedges				
Agropyron caninum	N	61.34 ± 12.44	22.31 ± 10.39	n/a
	S	50.63 ± 11.96	23.65 ± 8.88	n/a
	E	51.96 ± 11.07	2.85 ± 2.84	n/a
	W	53.74 ± 9.22	35.74 ± 16.09	n/a
Agropyron scribneri	S	19.29 ± 7.22	n/a	n/a
	W	20.79 ± 6.12	n/a	n/a
Carex atrata	N	23.4 ± 5.16	70.44 ± 13.38	t = 4.01*
	E	17.56 ± 5.30	81.73 ± 33.56	t = 3.61
Carex phaeocephala	E	20.98 ± 5.63	n/a	n/a
Deschampsia cespitosa	S	15.16 ± 5.98	n/a	n/a
Festuca idahoensis	N	21.30 ± 5.23	55.79 ± 14.77	t = 2.20*
	E	62.27 ± 11.31	64.72 ± 9.81	t = 0.16
	W	18.95 ± 6.53	89.61 ± 20.43	t = 3.29*
Leucopoa kingii	W	8.46 ± 2.63	16.67 ± 6.00	t = 1.33
Poa alpina	N	18.00 ± 3.81	25.10 ± 8.45	t = 0.87
Poa secunda	N	31.50 ± 5.38	21.94 ± 7.62	n/a
	S	26.44 ± 5.39	7.12 ± 7.12	n/a
	E	34.29 ± 10.89	5.90 ± 5.90	n/a
	W	27.30 ± 4.87	15.36 ± 7.91	n/a
Trisetum spicatum	N	25.48 ± 4.58	35.29 ± 9.48	t = 1.02
	E	39.71 ± 6.99	11.39 ± 11.39	n/a
	W	7.51 ± 2.65	7.32 ± 4.73	n/a
Spreading Forbs				
Achilliea millefolium	N	70.93 ± 5.71	45.69 ± 11.15	n/a
	S	44.98 ± 10.15	44.65 ± 15.07	n/a
	E	50.71 ± 6.56	20.14 ± 16.05	n/a
	W	51.59 ± 7.00	52.77 ± 14.51	t = 0.07
Antennaria umbrinella	S	6.00 ± 3.16	50.62 ± 18.22	t = 2.41
	W	9.66 ± 3.70	25.11 ± 10.30	t = 1.70
Artemesia scopulorum	N	27.22 ± 6.49	69.73 ± 11.20	t = 3.27*
Astragalus alpinus	N	14.89 ± 3.73	25.62 ± 9.34	t = 1.07
	S	4.16 ± 2.46	14.23 ± 4.83	t = 1.91
	W	17.18 ± 3.26	45.86 ± 15.24	t = 1.84
Cerastium beeringianum	N	40.59 ± 4.95	46.56 ± 7.71	t = 0.62
	S	9.44 ± 2.86	17.03 ± 8.54	t = 0.85
	E	41.25 ± 7.03	31.53 ± 5.59	n/a
	W	25.24 ± 5.06	52.83 ± 13.70	t = 2.24*
Phlox pulvinata	S	4.94 ± 2.28	20.24 ± 10.69	t = 1.40
	W	5.44 ± 2.83	25.71 ± 4.96	t = 3.19*

Table 4. (cont.)

Species	Aspect	Importance Value (mean ± s.e.) Road	Tundra	Significance‡
Sedum lanceolatum	S	14.95 ± 4.83	34.16 ± 13.23	t = 1.36
	E	9.40 ± 3.42	n/a	n/a
	W	28.56 ± 3.97	26.84 ± 6.30	n/a
Erect Forbs				
Agoseris glauca	S	7.18 ± 4.41	81.04 ± 11.09	t = 7.33*
	E	38.60 ± 8.32	28.47 ± 15.06	n/a
	W	8.31 ± 2.81	44.07 ± 15.47	t = 2.27
Artemesia michauxiana	S	9.93 ± 4.09	n/a	n/a
	W	14.72 ± 4.44	n/a	n/a
Erigeron compositus	W	3.56 ± 2.78	9.27 ± 3.36	t = 0.75
Geum rossii	N	7.68 ± 2.38	87.60 ± 18.41	t = 4.31*
	E	13.98 ± 5.88	40.69 ± 36.51	t = 0.72
	W	7.15 ± 2.16	56.81 ± 19.27	t = 2.56*
Lupinus argenteus	N	37.67 ± 8.58	33.46 ± 15.14	n/a
	E	33.94 ± 10.01	29.37 ± 21.41	n/a
Myosotis alpestris	N	24.83 ± 5.23	12.81 ± 4.08	n/a
	W	13.08 ± 3.67	23.27 ± 6.65	t = 1.23
Oxytropis lagopus	W	17.19 ± 4.39	58.24 ± 14.24	t = 2.76*
Penstemon whippleanus	W	4.05 ± 3.63	n/a	n/a
Phacelia alpina	S	9.49 ± 4.38	n/a	n/a
	W	5.16 ± 3.21	n/a	n/a
Phacelia sericea	S	17.60 ± 4.18	1.42 ± 1.42	n/a
	W	30.72 ± 4.99	1.22 ± 1.22	n/a
Polygonum bistortoides	N	18.14 ± 3.97	61.19 ± 9.69	t = 4.88*
	E	19.64 ± 4.64	80.76 ± 5.91	t = 5.60*
Potentilla diversifolia	N	40.09 ± 5.31	87.23 ± 7.51	t = 4.62*
	E	58.12 ± 6.06	68.19 ± 14.50	t = 0.67
	W	18.64 ± 3.18	47.74 ± 14.66	t = 1.94
Senecio canus	S	13.77 ± 4.22	5.69 ± 3.60	n/a
	W	6.84 ± 2.39	n/a	n/a
Solidago multiradiata	N	49.02 ± 5.96	66.64 ± 11.58	t = 1.43
	S	7.57 ± 3.59	2.95 ± 1.87	n/a
	E	45.69 ± 5.96	68.96 ± 26.79	t = 1.36
	W	9.91 ± 3.31	21.37 ± 33.25	t = 1.27

‡ independent samples t-test
* significant; $p < .05$

In 1980 and 1981, AMAX seeded unused roads with a seed mixture of 50% *Bromus inermis* and 50% *Agropyron intermedium* or with the slightly more diverse mixture of 30% *B. inermis,* 30% *Dactylis glomerata,* 15% *Phleum* pratense and 25% *Trifolium sp.* (Smith, 1995). Only trace amounts of *B. inermis* and *D. glomerata* were observed on south roads and no trace of *P pratense* was observed. No traces of *A. intermedium* were found either, but *Agropyron caninum* had aggressively colonized roads of every aspect (Appendix 1), primarily on fill slopes. The unusual distribution and dense cover of *A. caninum* on fill slopes leads me to suspect AMAX unknowingly seeded it instead of *A. intermedium.* I cannot be sure of this, however, because *A. caninum* is native to the surrounding tundra and hybrids used in reclamation are difficult to distinguish from native alpine strands (Lesica, 1995). The following paragraphs describe several, but not all, of the more successful native alpine species occupying road treatments on each aspect. To avoid being redundant, I have not included *A. caninum* in these descriptions. It should be noted, however, that this species was abundant in fill slopes on all aspects. Importance values of all road colonizers are listed by aspect and treatment in Appendix 1.

On the north side of Bald Mountain the grasses *Poa secunda* and *Trisetum spicatum* were successfully colonizing roads. These grasses appeared uninfluenced by treatment while *Poa alpina* was important only on cut slopes. Unlike the spreading forbs *Achillea millefolium and Cerastium beeringianum*, which thrived on all north side treatments, *Astragalus alpinus* did poorly on fill slopes. *A. alpinus* may be unable to compete for water and/or nutrients or its' seed may require light to germinate. The erect forbs *Lupinus argenteus* and *Solidago multiradiata* were also successful across treatments while *Myosotis alpestris* successfully colonized only cut slopes of this aspect.

On south aspects plant cover is low and forbs did not successfully colonize road centers. *Artemesia michauxiana*, a large shrubby forb, is more successful at colonizing road centers than other erect forb species. *Phacelia sericea* was clearly the most abundant erect forb colonizing cut slopes, and following *Senecio canus*, it was also the most successful on fill slopes. *Sedum lanceolatum* was the most "important" forb occupying the road center yet it had a much lower IV than any grass colonizer. *Deschampsia cespitosa* was an important colonizer as were the grasses *Agropyron scribneri* and *Poa secunda*.

On east aspects two sedges, *Carex atrata* and *Carex phaeocephala,* were successfully colonizing roads. *Festuca idahoensis* and several other grass species had successfully colonized all road treatments and grew amongst an several forbs. *Agoseris glauca, Solidago multiradiata, Potentilla diversifolia,* and *Lupinus argenteus* were thriving throughout the east side roads and *Geum rossii* was relatively well established in fill slopes. *Sedum lanceolatum* is less successful on road centers and fill slopes but *A. millefolium* and *C. beeringianum* are abundant on all treatments of the east facing roads.

On the west side of Bald Mountain the erect forb *Phacelia sericea* conspicuously colonized cut and fill slopes. *P sericea* displayed a similar colonization pattern on the south side of the mountain. *Artemesia michauxiana and Phacelia alpina* were also well established on both west and south aspects. These species were more successful on dry, southern and western aspects. The same was found for the grass *A. scribneri* and the spreading forbs *Antennaria umbrinella, Astragalus alpinus* and *Sedum lanceolatum.*

A complete list of revegetation candidates was compiled based upon the results of this section. Table 5 highlights the treatments and aspects in which each candidate was successful. The absence or low IV of a species on any treatment or aspect does not necessarily imply that it will not grow there. Other factors including ineffective seed dispersal may play an important role in some cases. The remainder of this paper addresses such issues.

Table 5. Final list of revegetation candidates according to aspect and treatment.

North	Treatment*	South	Treatment*	East	Treatment*	West	Treatment*
Grass/Sedge spp.		Grass/Sedge spp.		Grass/Sedge spp.		Grass/Sedge spp.	
Agropyron caninum	c,r,f	*Agropyron caninum*	c,r,f	*Agropyron caninum*	c,r,f	*Agropyron caninum*	c,r,f
Poa alpina	c	*Agropyron scribneri*	c,r,f	*Carex atrata*	f	*Agropyron scribneri*	c,r,f
Poa secunda	c,r,f	*Deschampsia cespitosa*	c,r,f	*Carex phaeocephala*	r,f	*Leucopoa kingii*	c
Trisetum spicatum	c,r,f	*Poa secunda*	c,r,f	*Festuca idahoensis*	c,r,f	*Poa secunda*	c,r,f
				Poa secunda	c,r,f	*Trisetum spicatum*	r,f
Erect Forbs				*Trisetum spicatum*	c,r,f		
Lupinus argenteus	c,r,f	Erect Forbs				Erect Forbs	
Myosotis alpestris	c	*Artemesia michauxiana*	c,r,f	Erect Forbs		*Agoseris glauca*	c,r
Solidago multiradiata	c,r,f	*Phacelia alpina*	c,f	*Agoseris glauca*	c,r,f	*Artemesia michauxiana*	f
		Phacelia sericea	c,f	*Geum rossii*	f	*Erigeron compositus*	r
Spreading Forbs		*Senecio canus*	c,f	*Lupinus argenteus*	c,r,f	*Myosotis alpestris*	c,r,f
Achillea millefolium	c,r,f	*Solidago multiradiata*	c,f	*Potentilla diversifolia*	c,r,f	*Phacelia alpina*	c
Astragalus alpinus	c			*Solidago multiradiata*	c,r,f	*Phacelia sericea*	c,r,f
Cerastium beeringianum	c,r,f	Spreading Forbs				*Penstemon whippleanus*	c
		Antennaria umbinella	c,f	Spreading Forbs		*Potentilla diversifolia*	c,r,f
		Cerastium beeringianum	c,f	*Achillea millefolium*	c,r,f	*Solidago multiradiata*	c,r
		Phlox pulvinata	c	*Cerastium beeringianum*	c,r,f		
		Sedum lanceolatum	c,r,f	*Sedum lanceolatum*	c	Spreading Forbs	
						Achillea millefolium	c,r,f
						Antennaria umbrinella	r,f
						Astragalus alpinus	c,r,f
						Sedum lanceolatum	c,r,f

* c = cut; r = road center; f = fill

Tundra Plant Community Types. TWINSPAN analysis of the data set suggests as many as nine distinct community types; however, follow-up analysis with DCA suggests that only three of these are well defined based upon species composition (Figures 3 & 4). The first indicator species was *Carex atrata* (eigenvalue = 0.386). *C. atrata* occurred on eleven of twenty-six transects, all which were located on north or east aspects. *Oxytropis lagopus* was the only species occurring on all other transects. No overlap between these species occurred. Except for two transects located on the summit of Bald Mountain with northerly aspects, all transects with *O. lagopus* faced south or west. The only other TWINSPAN division supported by DCA analysis used *Sibbaldia procumbens* as an indicator (eigenvalue = .208). Three transects had species associated with the community type indicated by *Sibbaldia procumbens* (SIBPRO).

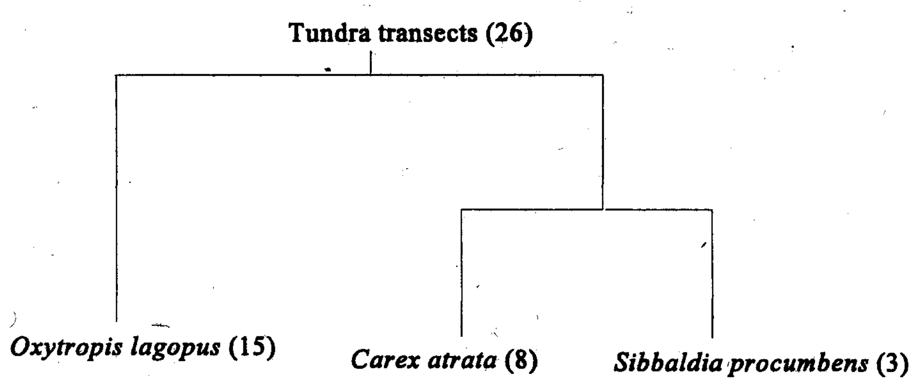

Figure 3. Dendrogram of 3 alpine plant community types classified using TWINSPAN. Indicator species are italicized and number of associated transects are enclosed in parentheses.

Several species demonstrated strong affiliations with one community type over another (Table 6).

Table 6. Average IV's of revegetation candidates in 3 alpine associations and in roads of similar aspect.

Candidate Species	OXYLAG	South Rds.	West Rds.	SIBPRO	CARATR	North Rds.	East Rds.
Grass/Sedge spp.							
Agropyron caninum	29.1	50.6	53.7	2.8	24.6	61.3	52.0
Agropyron scribneri	n/a	19.3	20.8	n/a	n/a	n/a	n/a
Carex atrata	n/a	n/a	n/a	81.7	88.0	23.4	17.6
Carex phaeocephala	n/a	n/a	n/a	n/a	n/a	n/a	21.0
Deschampsia cespitosa	n/a	15.2	n/a	2.8	20.1	n/a	n/a
Festuca idahoensis	84.6	n/a	18.9	64.7	50.8	21.3	62.3
Leucopoa kingii	19.4	n/a	8.5	n/a	n/a	n/a	n/a
Poa alpina	n/a	n/a	n/a	5.7	31.4	18.0	n/a
Poa secunda	10.0	26.4	27.3	5.9	27.4	31.5	34.3
Trisetum spicatum	4.6	n/a	7.5	11.4	40.9	25.5	39.7
Erect Forbs							
Agoseris glauca	62.2	7.2	8.3	28.5	30.6	n/a	38.6
Artemesia michauxiana	n/a	9.9	14.7	n/a	n/a	n/a	n/a
Erigeron compositus	19.4	n/a	3.6	n/a	n/a	n/a	n/a
Geum rossii	53.2	n/a	7.2	40.7	72.8	7.7	14.0
Lupinus argenteus	2.4	n/a	n/a	29.4	41.8	33.9	29.4
Myosotis alpestris	n/a	n/a	13.1	n/a	n/a	24.8	n/a
Penstemon whippleanus	n/a	n/a	4.1	n/a	n/a	n/a	n/a
Phacelia alpina	n/a	9.5	5.2	n/a	n/a	n/a	n/a
Phacelia sericea	1.14	17.6	30.7	n/a	n/a	n/a	n/a
Potentilla diversifolia	48.3	n/a	18.6	68.2	85.4	40.1	58.1
Senecio canus	5.7	13.8	6.8	n/a	n/a	n/a	n/a
Solidago multiradiata	14.0	7.6	9.9	69.0	75.6	49.0	45.7
Spreading Forbs							
Achillea millefolium	49.5	45.0	51.6	20.1	48.3	70.9	50.7
Antennaria umbrinella	33.1	6.0	9.7	25.6	6.4	n/a	n/a
Astragalus alpinus	34.6	4.2	17.2	2.85	21.9	14.9	n/a
Cerastium beeringianum	33.2	9.4	25.2	31.5	49.6	40.6	41.2
Phlox multiradiata	20.7	4.9	5.4	2.8	n/a	n/a	n/a
Sedum lanceolatum	25.1	14.9	28.6	n/a	n/a	n/a	9.4

While nine species were exclusively affiliated with the Oxytropis lagopus community type (OXYLAG), variation in species assemblages between stands was high (Figure 4).

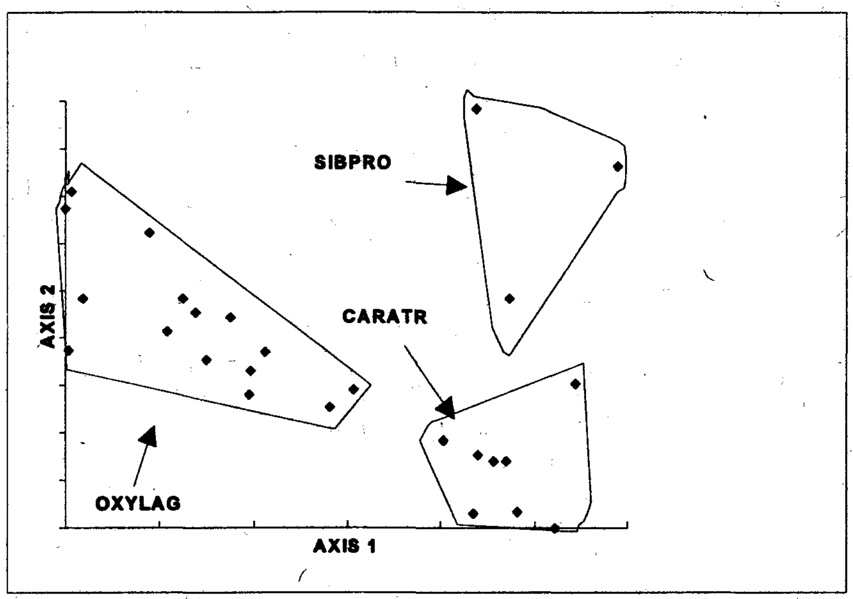

Figure 4. Scatterplot of 26 tundra transects ordinated using DCA. Each point in the ordination represents a specific tundra transect. DCA is designed so that variation between stands (transects) is indicated along Axis 1, not Axis 2. Variation between transects is indicated by spacial separation of points along Axis 1. Circles around points indicate transects of similar community types and were drawn according to divisions in species composition derived through TWINSPAN analysis. OXYLAG = *Oxytropis lagopus* community type, CARATR = *Carex atrata* community type, and SIBPRO = *Sibbaldia procumbens* community type.

The raw data indicated OXYLAG community types were found primarily on south and west aspects while CARATR and SIBPRO community types occurred only on north and east aspects. These latter two community types were floristically similar and differed primarily in the IV's of several species; most notably, *Sibbaldia procumbens, Agropyron caninum, Astragalus alpinus, Deschampsia cespitosa, Luzula spicata* and *Castilleja pulchello* (Table 6). Thilenius & Smith (1985) reported similar findings. They studied alpine plant communities on Carter Mountain: a mountain near Bald Mountain and of similar geologic origin. Although the community types found by Thilenius & Smith (1985) differed from the present study, many species identified in their study were found on Bald Mountain. Differences in geographic scale and disturbance history between the two study sites, however, render comparisons of these different community types difficult.

Tweit & Houston (1980) described five alpine community types as part of a classification of grassland and shrubland habitat types occuring on the Shoshone National Forest. Although the descriptions they provide of the *Festuca idahoensis (ovina)/Trisetum spicatum* and *Geum* turf community types are very general, many of the species associated with these types were found on Bald Mountain.

The long history of domestic sheep grazing followed by road building activities on Bald Mountain limit extrapolation concerning the successional status of its plant communities. However, the successional status of individual species can be inferred from species distribution patterns. *Poa secunda,* for example, appears to be early successional as its IV wanes from road to tundra on all aspects (Table 7). *F idahoensis* occupies both early and mid to late seres on mesic slopes; however, on xeric slopes it is important only in later seres. *Festuca idahoensis* may eventually colonize the roads on south and west aspects, but this may occur only after favorable micro-climatic conditions are created by early seral species.

Several tundra species exclusive to the OXYLAG community types colonized roads on south and west aspects. Some were revegetation candidates (Table 6). However, in no cases did species exclusive to OXYLAG community types colonize roads on north or east aspects.

It is improbable that resource competition limits species exclusive to OXYLAG community types from colonizing roads of north and east aspects because many of these roads are sparsely vegetated. Ineffective seed dispersal may limit some of these species to south and west slopes. Seeds of *Oxytropis lagopus* lack morphological characteristics for effective wind dispersal and may account for its absence from north and east aspects. An alternative hypothesis may be that OXYLAG species require a longer snow-free time period than is available on north and east aspects. Species exclusive to OXYLAG grow on aspects subjected to wind desication and direct sunlight. These species are well adapted to these conditions. Conversely, species of the SIBPRO community type may be well adapted to cold/wet site conditions. The three transects where SIBPRO communities were recorded were the last transects to be established because of late melting snow. *Erigeron perigrinus* was only recorded in the SIBPRO community type and is known to occur in bogs and wet tundra sites in Alaska (Alaback 1996).

Ubiquitous tundra species such as *Festuca idahoensis, Solidago multiradiata* and *Cerastium beeringianum* may have both wide ecological amplitude and efficient seed production/dispersal capabilities. That each of these species may be observed in non-alpine meadow communities may support this hypothesis. Water and/or wind, however, may limit *F. idahoensis* from successfully colonizing xeric south aspects on Bald Mountain.

Table 7 Average IV's of select species in 3 alpine species associations.

Species	Association Type OXYLAG n = 15	 CARATR n = 8	 SIBPRO n = 3
Poa sp.	64.9	4.3	5.7
Oxytropis lagopus	56.3	n/a	n/a
*Antennaria umbrinella**	33.1	6.4	25.6
Artemesia frigida	28.6	n/a	n/a
*Sedum lanceolatum**	25.1	n/a	n/a
*Phlox pulvinata**	20.7	n/a	2.8
*Erigeron compositus**	19.4	n/a	n/a
*Leucopoa kingii**	19.4	n/a	n/a
Koeleria cristata	8.0	n/a	n/a
Geum triflorum	3.5	n/a	n/a
Castelleja sulphurea	1.14	n/a	n/a
*Phacelia sericea**	1.14	n/a	n/a
*Achillea millefolium**	49.5	48.3	20.1
*Agoseris glauca**	62.2	30.6	28.5
*Festuca idahoensis**	84.6	50.8	64.7
*Potentilla diversifolia**	48.3	85.4	68.2
*Agropyron caninum**	29.1	24.6	2.8
*Astragalus alpinus**	34.6	21.9	2.8
Luzula spicata	97.0	23.6	86.0
Polygonum bistortoides	14.0	63.6	80.8
*Carex atrata**	n/a	88.0	81.7
Artemesia scopulorum	2.9	82.7	63.1
*Poa alpina**	n/a	31.4	5.7
Senecio lugens	0.6	21.1	8.75
*Deschampsia cespitosa**	n/a	20.1	2.8
Sibbaldia procumbens	0.6	12.9	43.0
Aster alpigenus	n/a	21.7	38.3
Castelleja pulchello	n/a	9.7	34.7
Erigeron peregrinus	n/a	5.2	n/a

* revegetation candidate

SECTION II. SOILS

FIELD METHODS

Wilson (1980) and Hausel (1982) identified zones on Bald Mountain where geologic material was subjected to intense hydrothermal alteration. Soils derived from hydrothermally altered rock generally have lower pH values and levels of available P than adjacent unaltered areas (Billings 1950, Salisbury 1954, Schlesinger et al. 1989). I collected soil samples to analyze these chemical properties in order to locate the hydrothermally altered zones on Bald Mountain. Soil samples were collected along transects established during vegetation sampling. Soil samples gathered from road transects were collected at 5cm depths from 4 to 6 random locations along each transect. Samples collected from each transect were consolidated, air-dried and sieved through a 2mm mesh sieve. Samples were stored at room temperature in wax-lined paper bags and marked for later laboratory analysis. Soil temperatures were recorded at a 5cm depths. Small soil samples (10-15 grams) were collected at 5cm depths along each transect and were moistened to assess soil texture according to particle size.

In order to minimize impact to tundra plant communities, methods for collecting soil samples along tundra transects differed from those described above . A soil pit was subjectively located along individual transects established during tundra vegetation sampling. At each soil sampling location, organic mats were carefully removed and a soil profile was exposed to bedrock. Soil was collected 5cm below the organic mat according to the methods described above. Descriptive data collected at each soil pit included: thickness of the O and A horizons, depth to C horizon, soil temperatures of mineral soil at 5cm and 15cm depths, and texture (feel method) of the A horizon.

LABORATORY METHODS. Soil (P) availability was determined colormetrically by testing for soluble P in dilute acid-fluoride solution (Bray & Kurtz, 1945). Soil pH was determined using the Glass Electrode-Calomel Electrode pH Meter Method (Page et. al, 1982).

RESULTS

Heavy machinery used for constructing roads on Bald Mountain removed all organic (O) soil horizons from the road centers. Remnants of these horizons are found on the densely vegetated fill slopes. Soil textures of fill slopes on north, east and west aspects were generally loam or sandy loam while road centers were generally sandy clay or sand. The dark mineral soils exposed in the cut slopes were mostly loam. Roads on the dry, wind-exposed south aspect originally had relatively thin organic horizons (Table 8), as was evident from sampling tundra on this aspect (Table 9). Soils from cut, road centers, and fill slopes of this aspect are mostly sand or clayey sand.

Sod clumps were abundant at the base of cut slopes on all aspects, but they seem most prolific on steeper southern slopes. Soil freeze/thaw activity is a common natural disturbance in alpine tundra (Johnson & Billings, 1962) and likely works in concert with the unnaturally steep cut slopes to release these tundra clumps from the cut slope edges. Where this activity occurs, the cut slopes become increasingly steep. Because vegetation is lost as sod clumps release, mineral soil becomes exposed and is removed by wind, rock slides, and snow avalanches in winter. The rapid loss of soil through such activity emphasizes the importance of timely reclamation with appropriate plant species.

The tundra of Bald Mountain had thick O horizons overlying deep mineral soils (Table 9). Soil temperatures taken from transects on north aspects were lower than expected (8-13°C; Bliss, 1985). Soil temperatures from other aspects were within this predicted range (Table 9).

While road and tundra pH values (mean 4.85 ± s.e. 0.07 and mean 4.83 ± s.e. 0.11, respectively) were not significantly different ($t = 0.10$, $p > .05$), three road sampling areas had pH values (mean 3.87 ± s.e. 0.06) significantly lower than other road areas ($t = 5.18$, $p < .05$). With the exceptions of low plant cover on T-5 road center and T-8 cut slope, transects with soil pH < 4.0 had the lowest vegetation cover of all road transects sampled. Low plant cover recorded for the road center of T-5 and cut slope of T-8 may be due to envirnomental factors associated with aspect and elevation, while a combination of these factors and soil pH likely account for the low plant cover in the road center and fill slope of T-8 (Table 2).

Soil from roads had significantly greater ($t = 6.34$, $p < .05$) P availability than soil from tundra (mean 2.02 ± s.e. 0.22 and mean 0.63 ± s.e. 0.04, respectively). Soil P availability increased significantly ($t = 4.74$, $p < .05$) in roads when pH fell below 4.0 (Figure 5). Although no rocks were collected for analysis, it is probable that these extremely acid soils are derived from hydrothermally altered rock (Lange 1996). The zones of hydrothermal alteration mapped by Hausel (1982) and Wilson (1980) are not precisely defined, but do correspond to the sites where these soil samples were collected.

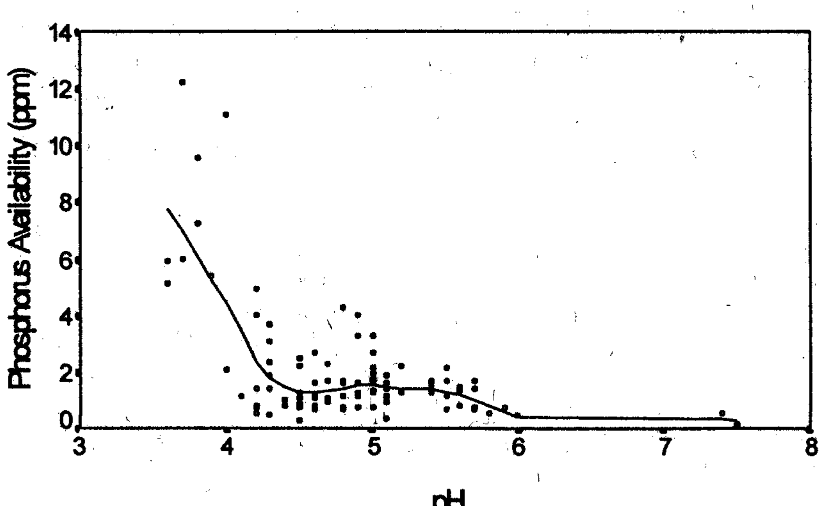

Figure 5. Scatterplot of pH and phosphorus availability in road transects. Each point in the scatterplot represents a road transect. Phosphorus availability was significantly greater when transects had soil pH values <4.

The significantly greater levels of available P in soils with lowest pH values was unexpected. The results, however, do not necessarily contradict findings by Billings (1950) and Salisbury (1954). While the pH of altered soils in Billings' (1950) study ranged between 3.5 and 5.5, his nutrient analysis used soils with pH 4.3. Data from Salisbury (1954) demonstrated that P availability increased significantly as soil pH dropped below 3.5. The increase in P availability once pH fell below a certain threshold may be explained by pH associated changes in minerolgy and the varying degree in which certain minerals (e.g. strengite & verasite) retain orthophosphate ions (Lindsay, 1979). A less complex alternative hypothesis is P availability was higher because few plants were present to utilize it.

Reduced chemical forms of aluminum (Al^{+3}) or other heavy metals are associated with extremely low soil pH (Lindsay, 1979). These metals are toxic to plants and may limit plant colonization and survival in soils where pH values were below 4. Although Al availability was not measured in the laboratory, the most commonly cited toxicity problem involving soil cations has been associated with aluminum concentrations in acidic soils (Tate, 1995). Furthermore, Al toxicity has been recently cited as a significant factor limiting plant distribution (Andersson, 1993; Andersson & Brunet, 1993). However, further nutrient analysis is necessary to support this hypothesis.

Table 8. Summary of soil data (mean ± s.e.) from Tundra transects.

Aspect	pH	Availability (ppm) Soil P	Thickness (cm) O- Horizon	Thickness (cm) A- Horizon	Depth (cm) to C- Horizon	Temperature °C 5cm	Temperature °C 15cm
North	4.44 ± 0.14	0.59 ± 0.08	6.25 ± .544	25.35 ± 2.28	37.70 ± 2.13	6.1 ± 0.31	4.5 ± 0.37
South	5.30 ± 0.09	0.62 ± 0.09	3.00 ± .516	24.16 ± 1.19	28.83 ± 0.79	11.2 ± 1.11	8.8 ± 0.83
East	4.10 ± 0.10	0.78 ± 0.10	8.33 ± 2.40	31.00 ± 2.65	42.67 ± 4.33	9.0 ± 1.73	6.3 ± 1.45
West	5.31 ± 0.04	0.66 ± 0.06	5.14 ± .595	25.43 ± 1.54	30.57 ± 1.66	8.8 ± 1.16	7.4 ± 0.84
mean ± s.e.	4.83 ± 0.11	0.64 ± 0.04	5.44 ± 0.48	25.75 ± 1.08	34.31 ± 1.39	8.35 ± 0.58	6.5 ± 0.49

Table 9. Summary of soil data (mean ± s.e.) from Road transects.

Aspect	pH	Availability (ppm) Soil P	Temperature (°C) 5cm
North	4.47 ± 0.06	2.22 ± 0.56	9.8° ± 0.68
South	4.88 ± 0.10	2.70 ± 0.37	8.8° ± 0.84
East	4.64 ± 0.07	1.58 ± 0.15	12.5° ± 0.84
West	5.29. ± 0.16	1.60 ± 0.27	7.1° ± 0.57
Treatment			
Cut	4.95 ± 0.10	1.82 ± 0.32	7.84 ± 0.70
Road	4.80 ± 0.13	2.17 ± 0.41	11.03 ± 0.67
Fill	4.79 ± .012	2.10 ± 0.39	8.46 ± 0.53

SECTION III. SEED

FIELD METHODS

Seeds of several forb species were collected between late August and early September. Numerous publications exist that cite the germination requirements of alpine grasses found growing on the study site (Acharya, 1989; Chambers et al., 1987; Clebsch & Billings, 1976; Wester, 1991); therefore, seed of grass species were not collected. Forbs selected for seed collection included *Agoseris glauca, Artemesia michauxiana, Astragalus alpinus, Lupinus argenteus, Oxytropis lagopus, Phacelia hastata* var. *alpina, Phacelia sericea, Senecio canus, Senecio lugens* and *Solidago multiradiata.* These species were selected based upon field observations of consistent road colonization, appealing morphological characteristics for revegetation and ease of seed collection. Seeds were collected by hand when ripe or by loosely placing soft mesh fabric around the flowering heads following peak anthesis. Fabric was secured using paper coated copper wire. Following dispersal, seeds captured in the mesh fabric was collected by cutting the plant stems below the flowering heads. All collected seeds were stored at room temperature in paper bags for three weeks. Once dried, seeds were cleaned using a pneumatic air separator and were stored dry in black viles at 4°C until initiation of germination and viability tests.

LABORATORY METHODS

Germination Experiments. Germination responses to light and cold stratification were investigated for *Solidago multiradiata*, *Agoseris glauca*, *Lupinus argenteus*, *Oxytropis lagopus* and *Phacelia sericea*. Seed from other species could not be tested for germination due to phenologic immaturity (*Artemesia michauxiana*), insect infestation (*Senecio canus, Senecio lugens*), non-filled seed (*Phacelia hastata* var. *alpina*) or insufficient sample size (*Astragalus alpinus*).

Germination trials involved 45 days of dry cold storage or wet cold storage (stratification) treatment followed by a 34-day growth chamber treatment in light or dark conditions with "daytime" temperatures of 25°C (14 hours) and "night-time" temperatures of 5°C (10 hours). Two hundred seeds of each of the five species were placed on Whatman's #40 filter paper inside glass petri dishes. Distilled water was used to water the seeds and filter paper for the stratification treatment. All petri dishes were placed in a light-proof container and stored at 4°C. Stratification treatments continued throughout the growth chamber testing period. Seeds killed by mold or fungus were counted and removed, so sample size varied between species. The initial observation was made after 18 days and subsequent observations were made every 3 to 4 days. Filter paper was changed frequently to reduce mold or fungus infestation. Seeds were checked for germination and those receiving wet stratification treatment were re-moistened if necessary. All excess water was removed and seeds damaged by mold or fungus were counted and discarded. A seed was considered to have germinated if either the radicle or cotyledon had emerged 1 mm beyond the seed coat.

Following the 45-day cold storage treatment, non-germinated seeds were moved into a Conviron PGW-36 growth chamber. Seeds were evenly divided for light and dark growth chamber treatments. The light-treated seeds received 14 hours of light provided by "cool-white" fluorescent bulbs located overhead. Dark-treated seeds were housed in a light-proof box within the growth chamber and were observed only under a green safe-light. Seeds receiving stratification treatment were re-moistened when necessary and seeds in all four treatments were examined for germination every second day for 38 days.

Viability, Dormancy, and Additional Germination Tests.

Five replications of 20 seeds each from *Solidago multiradiata, Agoseris glauca* and *Lupinus argenteus* were tested for viability. Following a 90-day pre-chill treatment at 4°C, seeds were soaked in water for 18-24 hours then immersed in a 1% aqueous solution of tetrazolium chloride (TZ). Seeds were left in the dark at 30°C for 3-6 hours. Seeds with completely stained embryos were considered viable.

Further tests of seed viability and germination responses were conducted at the Montana State University (MSU) Seed Lab on *Oxytropis lagopus*, *Agoseris glauca* and *Phacelia sericea*. Viability test procedures at MSU were similar to those listed above; however, the pre-chill treatment was applied for an additional 14 days (total 104 days). Viability was investigated using five replications of 40 seeds for each species. Germination response following 14 days exposure to alternating temperatures (8 hours/25°C and 16 hours/15°C) were recorded. Four replications of 100 seeds for each species were tested.

Seeds which failed to imbibe water or germinate were tested for dormancy TZ tests were performed on species lacking hard seed coats and those with embryos stained red were considered viable, yet dormant. Seeds of species with hard seed coats were also considered dormant. Hard seeds were counted and recorded as were "dead" seeds. Hard seeds were labeled such if the seed coat required substantial force to penetrate. Dead seeds had "mushy" seed coats, were infested by mold or fungus, or showed no evidence of sprouting.

RESULTS

Germination Experiments. For all species germination occurred only when wet treatment was applied. Zero (0) seeds achieved germination following dry treatment in either cold storage or in growth chamber treatments. Many seeds receiving wet treatment were killed by mold or fungus in the first two weeks of the experiment; particularly *Solidago multiradiata* (67) and *Agoseris glauca* (64). Losses were less for *Oxytropis lagopus* (18), *Phacelia sericea* (12) and *Lupinus argenteus* (6). Germination responses to cold wet treatment were low for all species except for *Lupinus argenteus* (Table 10).

Germination response to fluctuating temperatures and light or dark growth chamber conditions were low except in dark conditions for *S. multiradiata* (64%) and *L. argenteus* (72%). For both species, germination of 50% of the samples were achieved after 12 days of fluctuating temperatures and dark conditions (Table 11).

Viability, Dormancy, and Additional Germination Tests.

Follow-up investigations of species which failed to achieve germination of 50% of the sample revealed that each of the three species (*Phacelia sericea*, *Oxytropis lagopus* and *Agoseris glauca*) had some dormancy mechanism. Although low mean germination of *P sericea* (13%), *O. lagopus* (17%), and *A. glauca* (15%) following fluctuating temperature treatments supported the results found in the previous germination tests, viability in all three species was relatively high. Mean total viability for *A. glauca*, *P. sericea,* and *O. lagopus* was 75%, 73%, and 91%, respectively. Only seed of *O. lagopus* required scarification for "hard" seed. Seed not requiring scarification to stain during TZ tests were deemed "normal." "Normal" and "hard" seed counts were combined and calculated to produce total viability scores. Viability tests for the non-dormant species *Lupinus argenteus* and *Solidago multiradiata* revealed mean total viability of 86% and 76%, respectively (Table 12).

Table 10. Germination response to cold wet storage.

Days	*Phacelia sericea* (n=188)	*Oxytropis lagopus* (n=182)	*Agoseris glauca* (n=136)	Solidago multiradiata (n=133)	Lupinus argenteus (n=194)
18	0	15	6	0	20
22	0	0	2	3	6
25	1	6	1	1	19
29	4	1	1	0	19
32	7	3	2	0	19
35	2	0	6	3	16*
39	2	3	0	6	30
43	0	1	1	0	20
49	1	2	1	2	9
TOTAL	17	31	20	15	142
% Germ	**9%**	**17%**	**15%**	**11%**	**81%**

*50% of sample achieved germination

Table 11. Germination response to light vs. dark growth chamber conditions.

Days	*Phacelia sericea* Light (n=85)	*Phacelia sericea* Dark (n=85)	*Oxytropis lagopus* Light (n=75)	*Oxytropis lagopus* Dark (n=75)	*Agoseris glauca* Light (n=58)	*Agoseris glauca* Dark (n=58)	*Solidago multiradiata* Light (n=59)	*Solidago multiradiata* Dark (n=59)	*Lupinus argenteus* Light (n=18)	*Lupinus argenteus* Dark (n=18)
3	0	0	0	0	0	1	0	24	3	6
7	0	0	1	0	0	0	0	1	0	0
9	0	1	0	0	0	0	1	2	0	1
12	1	0	1	3	0	0	0	6*	0	2*
14	0	0	1	2	0	1	0	1	0	0
15	0	0	0	1	1	0	0	0	0	0
17	0	0	0	0	0	0	8	3	0	3
18	0	0	0	1	0	2	3	0	1	0
21	0	0	0	0	0	1	5	0	0	0
23	0	0	0	0	3	0	2	0	0	0
24	0	0	0	0	0	0	1	0	0	0
26	0	0	0	0	2	1	1	0	0	0
28	0	0	0	1	3	0	0	0	1	0
31	0	0	0	0	2	0	0	1	0	1
34	0	0	0	1	1	2	0	0	0	0
TOTAL	1	1	3	9	12	8	21	32	5	11
% Germ	**1%**	**1%**	**4%**	**12%**	**21%**	**14%**	**35%**	**64%**	**27%**	**72%**

*50% of sample achieved germination

Table 12. Viability and dormancy results.

SPECIES	GERMINATION† (mean ± s.e.)	NORMAL SEED (mean ± s.e.)	HARD SEED (mean ± s.e.)	TOTAL VIABILITY (mean ± s.e.)	CONFIDENCE INTERVAL (alpha = .025, P = 97.5)	DORMANCY (type)
*Agoseris glauca**	0.15 ± .039	0.75 ± .059	n/a	0.75 ± .059	$.58 < \mu < .91$	physiologic
Lupinus argenteus	n/a	n/a	n/a	0.86 ± .037	$.76 < \mu < .96$	none
*Oxytropis lagopus**	0.17 ± .009	0.06 ± .123	0.85 ± 0 .02	0.91 ± .014	$.88 < \mu < .95$	seed coat
*Phacelia sericea**	0.13 ± .041	0.93 ± .016	n/a	0.93 ± .016	$.88 < \mu < .97$	physiologic
Solidago multiradiata	n/a	n/a	n/a	0.76 ± .025	$.69 < \mu < .83$	none

*species tested at MSU seed lab.

† seeds exposed to 14 days fluctuating temperatures of 8hrs. @ 25°C and 16hrs. @ 15°C.

DISCUSSION

The results of this investigation strongly implicate a number of species suitable for revegetating the roads above treeline on Bald Mountain. A complete list of revegetation candidates is provided in Table 5. Many of the candidate species are important components of the surrounding tundra although a few exceptions exist.

Phacelia sericea was the most notable exception. It colonized roads on xeric south and west aspects but was found in only trace amounts in the tundra of these aspects. The grass *Agropyron scribneri* and the forbs *Artemesia michauxiana* and *Phacelia hastata* var. *alpina* were also successful on roads of south and west aspects but were completely absent from the surrounding tundra. Because seeds of both *Phacelia spp.* are poorly designed for long-distance wind dispersal, I suspect that their seed source was the soil seed bank. Adequate amounts of mineral soil were present on the roads and could serve as seed bank.

Unfortunately, field observations suggest this is not the case on the steep slopes located <u>between</u> the road switchbacks on the south aspect. Prior to road construction these areas probably supported plant species and soil properties similar to what was recorded in tundra plots on this aspect. Following road construction the combination of receding cut slopes, soil erosion, wind exposure, and snow avalanches have prevented site recovery and continue to promote the loss of both vegetation and soil. In these sparsely vegetated areas, seed rain, as Cargill & Chapin (1987) suggest, may be the only natural source of disturbance colonizers. However, disturbance colonization may be enhanced when a seed bank is present (Cargill & Chapin 1987). Seed banks can be mimicked by appropriate seeding methods. Seeding methods for alpine and arctic tundra restoration have recently been documented (Vander Meer 1995) and could promote plant colonization in areas where seed banks are unavailable.

Seed bank absence does not account for the lack of vegetation cover on zones where soils are hydrothermally altered. Although the acid soil conditions in these altered zones occurred naturally, I propose that these zones were vegetated prior to road building. Over thousands of years, vegetative turnover and the gradual accumulation of organic matter ameliorated the naturally acid soil conditions, allowing a greater variety of plants to establish. When heavy machinery used to construct roads removed the organic horizons overlying altered soils on Bald Mt., this long-term ameliorative process was erased. Similar soil modification and formation processes were proposed by Salisbury (1964) for hydrothermally altered soils near Marysvale Canyon, Utah. Salisbury further proposed that once vegetation established the altered soil would eventually develop a profile similar to those found in the surrounding unaltered soil. Any future attempts in revegetating the altered soils on Bald Mountain will probably fail unless efforts focus on improving soil conditions in conjunction with selecting appropriate species. Full nutrient amendments may promote plant growth in these deficient soils (Billings 1950) but incorporating biosolids may be more appropriate for chelating toxic Al cations and improving important physical soil characteristics like water holding capacity.

Fortunately, vegetation recovery on most of Bald Mt. is not constrained by these soil characteristics. Numerous species are colonizing the majority of roads with various degrees of success. That many species are limited to certain aspects suggests that several factors contribute to this pattern. Dispersal of species exclusive to north and east aspects may be limited by northeast prevailing winds. Physiological limitations of some species may limit their establishment on xeric south and west slopes. Other species, including *Cerastium beeringianum* and *Solidago multiradiata* are ubiquitous in both well-developed tundra communities and road disturbances of all aspects. The widespread distribution of these species indicates that they are not only effective competitors, but they have highly effective seed dispersal mechanisms. Perhaps their seed dormancy mechanisms are just as important to their success.

Seed dormancy preserves a species during conditions unfavorable to survival of the germinant (Amen 1966). In a seminal paper addressing the role of seed dormancy in alpine plants, Amen (1966) states "...seed dormancy not only insures survival and perpetuation of a species, but also may secure for that species a prominent or even dominant position in the community". He found that many alpine species known to exhibit seed dormancy are dominant species in tundra communities. These species may have an ecological advantage over non-dormant species because dormant species may be able to spread germination over an extended period and germinate during several intervals favorable for growth. Non-dormant species, on the other hand, would tend to germinate simultaneously and would be subjected to higher mortality rates (Amen 1966).

The most common causes of dormancy in seeds are the physiological immaturity of the embryo and the impermeability of the seed coat to water and, sometimes, to oxygen (Raven et al. 1986). Several other dormancy mechanisms exist including chemical inhibitors, specific temperatures and light or dark requirements (Salisbury & Ross 1992). The mechanisms of seed dormancy in alpine plants appear to be as diverse and as common as for any other ecological group, and seed coat inhibition is probably the most common cause of dormancy (Amen 1966). Amen (1966) suggests that this dormancy mechanism evolved in response to alpine soil disturbances such as solifluction and wind turbulence at the soil surface.

That dormancy mechanisms may account, in part, for successful widespread species distribution and disturbance colonization poses a potential problem to those interested in expediting plant establishment through sowing seed. However, given the climatic constraints of alpine environments it would be unrealistic to expect rapid results following revegetation efforts. The most effective approach to ensuring successful long-term revegetation results may involve including a high diversity of species having revegetation potential. Once revegetation candidates have been identified, knowledge of the seed ecology of these candidates can be easily applied to revegetation strategies.

For example, results from the growth chamber experiment indicate that seeds of all species except *L. argenteus* had some dormancy mechanism. Only for *O. lagopus* was the dormancy mechanism discovered (Table 12); however, vegetation analysis indicates that *O. lagopus* is a poor revegetation candidate (Tables 3 & 4). *L. argenteus* seed germinated readily once moisture was applied. Once seed pods dry and release seed in the fall, seeds of *L. argenteus* may germinate as soon as adequate moisture is supplied via rainfall. Revegetation efforts should mimic this event by collecting and sowing ripe seed in the fall. Results from the growth chamber experiment indicate that germination may be inhibited under light conditions, so seed burial just below the soil surface may increase germination success. That this species does not occur on south aspects is not surprising considering the seeds' need for adequate moisture. Sowing should be limited to less xeric aspects.

Appropriate temperatures and dark growth chamber conditions promoted germination of *S. multiradiata* seed. The high importance value of *S. multiradiata* in densely vegetated fill slopes relative to more sun exposed cut slopes and road centers supports that dark conditions enhance germination (Figures 3-6). Its substantial contribution to densely vegetated tundra communities provide additional support (Table 7). The widespread distribution of *S. multiradiata* is attributed at least in part, to this dormancy mechanism and its morphological attributes for effective wind dispersal (pappus & light weight). The implications for revegetation based on these results are that germination success will be enhanced when seeds of *S. multiradiata* are buried just below the soil surface to avoid exposure to sunlight. *S. multiradiata* should be seeded on all aspects.

Implications for revegetation using *A. glauca* and *P sericea* are less apparent.

Both species were dormant (Table 12), and the mechanisms were not discovered. Their seed morphology and distribution on Bald Mt., however, provides valuable insight into seeding methods. *A. glauca* seeds are dispersed by wind. The seeds are light and because of their large pappus, may not bury below the soil surface easily. *A. glauca*'s importance value on east and west aspects appears uninfluenced by treatment (Appendix 1) indicating that light may not be a factor influencing germination. I suggest that fall sowing and shallow burial to prevent wind re-distribution is appropriate when revegetating with *A. glauca* seed. In comparison, *P. sericea* seeds are small and lack pappus. Field observation of their clumped distribution indicates that gravity is their primary dispersal agent. *P sericea* successfully colonized roads on south and west aspects, where diurnal temperature fluctuations are greatest. This combination of locale and small seed size suggests that seed are highly susceptible to sub-surface burial following soil freeze/thaw events and that shallow burial may enhance germination following sowing. Since seed dispersal for this species occurs in the early fall, revegetation timing should follow suit.

Although germination experiments were conducted on relatively few of the revegetation candidates listed in Table 5, the results are useful for making revegetation recommendations involving these species. A literature search into germination requirements for candidates not investigated in this study was conducted and germination requirements for several species were found. It should be noted, however, that both dormancy and germination requirements may differ between populations of the same species, particularly when strong latitudinal differences occur (Amen 1966, Clebsch & Billings 1976). Nonetheless, any autecological data available on revegetation candidates is useful. Dormancy and germination requirements for all revegetation candidates, including seed sources, are provided, when available in Appendix 2.

Land managers implementing site restoration should not let the complex processes of seed germination requirements and dormancy interfere with decisions regarding species selection. The seed biology information provided here is used simply to help guide decisions regarding seeding methods or plant propagation in the greenhouse.

The species recommended for revegetating road disturbances on Bald Mountain (Table 5) were found to be the most successful disturbance colonizers based upon my methods and analysis. Table 5 is organized to give land managers flexibility when deciding where revegetation efforts on Bald Mountain should focus. If, for example, the steep slopes between roads on the south aspect take priority then all species listed in Table 5 for the south aspect should be used. If stabilizing receeding cut slopes take priority, species identified as successful cut slope colonizers should be used.

While revegetation is the primary means of re-building and stabilizing soils following disturbance, a primary goal of revegetation should also include jump-starting the recovery of biological processes. The importance of seeding a wide diversity of species to achieving this goal is strongly emphasized. In addition to promoting biological processes, diverse plant assemblages are more resilient to natural disturbance and annual climatic variation than less diverse communities (Tilman, 1996). In considering the objectives of Ecosystem Management, this holistic approach to revegetating disturbed areas should be the rule, rather than the exception. Taking an ecological approach to restoring disturbed sites allows us to address multiple ecosystem values. Furthermore, applying knowledge of ecological processes to land reclamation greatly improve our chances of success.

APPENDICES

Appendix 1. Mean importance value of road colonizers across aspects and treatments.

	North Aspect (cut-off value = 20)			South Aspect (cut-off value = 7)			East Aspect (cut-off value = 20)			West Aspect (cut-off value = 10)		
Species	Cut Slope	Road Center	Fill Slope	Cut Slope	Road Center	Fill Slope	Cut Slope	Road Center	Fill Slope	Cut Slope	Road Center	Fill Slope
Achillea millefolium	63.3	65.5	83.9	37.1	42.7	55.2	48.1	63.3	40.7	33.5	63.8	57.5
Agoseris glauca	40.4	16.8	19.4	14.6	4.1	2.8	55.9	28.6	31.4	11.3	11.0	2.7
Agropyron caninum	16.1	34.7	133.3	48.6	41.6	61.7	34.5	34.4	87.0	34.3	41.6	85.3
Agropyron scribneri	0.0	0.0	0.0	8.8	17.5	31.6	0.0	0.0	0.0	20.7	14.5	27.2
Antennaria umbrinella	1.3	5.3	7.8	7.3	1.8	8.9	5.1	10.4	2.6	2.0	19.8	7.2
Artemesia frigida	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Artemesia michauxiana	0.0	0.0	1.3	7.7	7.5	14.7	0.0	0.0	0.0	4.0	5.3	34.8
Artemesia scopulorum	49.9	29.0	2.8	0.0	0.0	0.0	18.1	13.2	15.1	0.0	0.0	1.5
Astragalus alpinus	26.5	14.2	3.9	1.8	3.7	7.0	8.3	8.3	5.8	10.7	27.1	13.7
Aster alpigenus	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bupleurum americanum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	1.3	2.6
Calamagrostis purpuras	3.9	1.4	11.8	0.0	0.0	0.0	0.0	0.0	5.3	1.5	0.0	0.0
Carex atrata	31.1	27.5	11.6	0.0	0.0	0.0	13.0	16.1	23.6	0.0	0.0	0.0
Carex phaeocephala	0.0	0.0	3.1	0.0	0.0	0.0	10.3	22.9	29.8	2.7	1.3	0.0
Castilleja pulchello	1.3	0.0	0.0	0.0	0.0	0.0	0.0	7.7	2.6	0.0	0.0	0.0
Castilleja sulphurea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.7	4.1	0.0
Cerastium beeringianum	48.0	30.0	43.8	7.6	3.8	16.9	47.3	40.3	36.3	29.1	21.9	24.7
Deschampsia cespitosa	12.3	5.2	5.7	12.5	18.0	15.0	6.8	13.2	5.8	0.0	0.0	0.0
Erigeron compositus	0.0	2.6	0.0	0.0	1.8	0.9	2.6	8.1	0.0	1.9	22.0	3.9
Erigeron gracilis	2.6	3.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Erigeron peregrinus	3.8	4.0	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Festuca idahoensis	43.0	16.8	4.2	2.0	0.0	2.1	65.4	41.6	79.9	19.9	20.5	16.4
Geum rossii	6.6	3.9	12.5	4.0	3.8	5.3	2.6	2.6	36.8	6.7	5.5	9.3
Geum triflorum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	0.0	0.0
Juncus drummondii	16.5	9.6	0.0	0.0	0.0	0.0	5.5	2.8	0.0	0.0	0.0	0.0
Koeleria cristata	0.0	0.0	0.0	0.0	0.0	0.0	2.8	0.0	0.0	0.0	0.0	0.0
Luzula spicata	1.3	0.0	0.0	0.0	0.0	0.0	5.1	10.3	0.0	0.0	0.0	0.0
Leucopoa kingii	0.0	0.0	0.0	5.7	2.0	0.9	3.0	0.0	0.0	11.7	4.4	9.3
Lilly sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lupinus argenteus	26.1	51.3	35.6	0.0	0.0	0.0	27.8	50.2	23.9	5.2	6.3	2.8
Moss sp.	37.2	6.1	0.0	0.0	0.0	0.0	5.3	0.0	0.0	1.4	2.6	1.3
Myosotis alpestris	38.6	19.2	16.7	1.8	1.8	3.7	0.0	15.6	10.3	10.9	15.5	12.9
Oxytropis lagopus	0.0	0.0	0.0	0.0	0.0	0.9	0.0	2.6	5.8	11.3	23.5	16.8
Pedicularis bracteosa	3.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pedicularis groeulandica	0.0	0.0	0.0	0.0	0.0	0.0	5.1	0.0	0.0	0.0	0.0	0.0
Penstemon procerus	1.3	1.3	2.7	0.0	0.0	0.0	16.4	7.7	13.2	0.0	0.0	1.6

Appendix 1 cont.

	North Aspect (cut-off value = 20)			South Aspect (cut-off value = 7)			East Aspect (cut-off value = 20)			West Aspect (cut-off value = 10)		
Species	Cut Slope	Road Center	Fill Slope	Cut Slope	Road Center	Fill Slope	Cut Slope	Road Center	Fill Slope	Cut Slope	Road Center	Fill Slope
Penstemon whippleanus	0.0	0.0	0.0	1.8	0.0	0.0	0.0	0.0	0.0	10.9	1.3	0.0
Phacelia alpina	0.0	0.0	0.0	18.0	0.0	10.5	0.0	0.0	0.0	13.9	0.0	1.6
Phacelia sericea	2.6	0.0	0.0	28.6	3.8	20.4	5.1	5.1	5.1	37.1	16.6	38.4
Phleum alpinum	13.3	6.4	3.8	0.0	0.0	0.0	2.6	5.3	0.0	0.0	0.0	0.0
Phlox multiradiata	2.7	4.2	0.0	12.4	2.4	0.0	0.0	0.0	0.0	6.0	10.3	0.0
Pinus albicaulis	0.0	0.0	0.0	0.0	0.0	7.1	0.0	0.0	0.0	0.6	0.0	0.0
Poa alpina	31.4	13.4	9.2	0.0	3.7	0.0	0.0	2.6	0.0	0.0	0.0	0.0
Poa secunda	28.4	22.9	43.2	11.0	41.1	27.3	25.4	30.4	47.1	15.6	25.6	40.8
Poa sp.	13.1	2.8	11.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Polygonum bistortoides	36.2	5.1	13.1	0.0	0.0	0.0	25.6	7.7	25.6	0.0	0.0	1.3
Polemonium viscosum	11.5	1.3	5.2	3.8	0.0	0.0	2.6	0.0	16.9	1.3	0.0	2.9
Potentilla concinna	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.6	0.0	0.0	1.3
Potentilla diversifolia	44.6	39.8	36.0	3.8	3.7	5.6	72.3	51.6	50.4	17.5	18.7	19.7
Ribes sp.	0.0	0.0	0.0	0.0	0.0	1.6	0.0	0.0	0.0	1.9	0.0	0.0
Rumex salicifolius	0.0	0.0	0.0	15.9	9.6	22.7	0.0	0.0	0.0	0.0	1.3	1.3
Sedum lanceolatum	7.8	5.1	1.3	22.0	12.8	10.1	20.5	5.1	2.6	28.8	33.5	23.3
Senecio canus	1.3	0.0	0.0	13.4	5.5	22.5	0.0	0.0	0.0	5.8	3.8	10.9
Senecio fremontii	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	4.0	1.3	1.5
Senecio lugens	16.3	3.9	4.0	0.0	0.0	0.0	13.8	2.6	8.3	0.0	0.0	0.0
Sibbaldia procumbens	2.7	7.8	3.8	0.0	0.0	0.0	5.5	13.8	8.1	0.0	0.0	0.0
Solidago multiradiata	41.2	46.9	59.0	7.3	5.5	9.9	37.4	46.1	53.6	8.1	16.3	5.4
Taraxacum sp.	1.3	1.3	0.0	0.0	20.8	11.5	0.0	5.1	2.6	1.3	7.2	7.7
Thistle sp.	0.0	0.0	0.0	5.5	1.8	0.0	0.0	0.0	0.0	2.0	3.8	4.2
Townsendia parryi	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.6	1.3	0.0
Trisetum spicatum	20.9	36.7	18.9	2.0	4.0	4.7	29.2	44.1	45.8	1.3	12.1	9.2

Appendix 2. Germination and dormancy of Bald Mt. revegetation candidates as found in the literature.

Species	Temperature†	Light Treatment	Seed Source	Pre-treatment	Dormancy	Reference
Grass/Sedge						
Agropyron caninum	-	-	-	-	-	-
Agropyron scribneri	-	-	-	-	-	-
Carex atrata	-	-	-	-	-	-
Carex phaeocephala	-	-	-	-	-	-
Deschampsia cespitosa	18/4	L	Beartooth Plateau, MT	Cold Stratification	-	Chambers et al 1987
Festuca idahoensis	18/4	L, D	Beartooth Plateau, MT	Cold Stratification	-	Chambers et al 1987
Leucopoa kingii	-	-	-	-	-	-
Poa alpina	22/15	D	Alberta, Canada	-	-	Acharya, 1989
*Poa secunda**	-	-	-	-	-	-
Trisetum spicatum	20	D	Medicine Bow Mtns, WY	-	-	Clebsch & Billings, 1976
Erect Forbs						
Agoseris glauca	-	-	Absaroka Mtns., WY	-	Physiological	current study
Artemesia michauxiana	-	-	-	-	-	-
Erigeron compositus	-	-	-	-	-	-
Geum rossii	18/4	L	Beartooth Plateau, MT	Cold Stratification	-	Chambers et al., 1987
Lupinus argenteus	25/5	D	Absaroka Mtns., WY	Cold Stratification	-	current study
Myosotis alpestris	-	-	-	-	-	-
Penstemon whippleanus	-	-	Summit Lake, CO	-	Physiological	Bonde, 1965
Phacelia alpina	-	-	-	-	-	-
Phacelia sericea	-	-	Absaroka Mtns, WY	-	Physiological	current study
Potentilla diversifolia	18/4	L	Beartooth Plateau, MT	Cold Stratification	-	Chambers et al., 1987
Senecio canus	-	-	-	-	-	-
Solidago multiradiata	25/5	D	Absaroka Mtns, WY	Cold Stratification	-	current study
Spreading Forbs						
Achillea millefolium	21/10	L/D	North Dakota	Cold stratification	-	Hoffman & Hazlett, 1977
Antennaria umbrinella	21	D	British Columbia, Canada	-	Seed coat	McLean, 1967
Astragalus alpinus	-	-	-	-	-	-
Cerastium beeringianum	-	-	Rollins Pass, CO	after-ripening	Physiological	Bonde, 1965
Phlox multiradiata	-	-	-	-	-	-
Sedum lanceolatum	-	-	-	-	-	-

† Temperature(°C) used to promote germination. Some studies investigated optimal temperatures for germination while others only used one temperature setting. Backslashes separate high and low temperatures, respectively.

‡ Optimal light conditions found in the study cited for promoting germination. L = light conditions; D = dark conditions. Backslash indicates alternating light and dark conditions were used to promote germination while a comma indicates that germination was not significantly influenced by light vs.dark conditions.

* Methods for planting seed of *P. secunda* cited in Hull, 1948.

Appendix 3. List of all species observed in the alpine zone of Bald Mountain.

Erect Forbs

Agoseris glauca
Artemesia michauxiana
Aster alpigenus
Bupleurum americanum
Castelleja pulchello
Castelleja suphurea
Chaenactis alpina
Erigeron compositus
Erigeron gracilis
Erigeron peregrinus
Geum rossii
Geum triflorum
lilly spp
Lupinus argenteus
Myosotis alpestris
Oxytropis lagopus
Pedicularis bracteosa
Pedicularis groeulandica
Penstemon procerus
Penstemon whippleanus
Phacelia hastata var. alpina
Phacelia sericea
Polygonum bistortoides
Polemonium viscosum
Potentilla concinna
Potentilla diversifolia
Rumex salicifolius
Senecio canus
Senecio fuscatus
Senecio fremontii
Senecio lugens
Solidago multiradiata
Taraxacum sp
thistle
Townsendia parryi

Spreading Forbs

Achilliea millefolium
Antennaria umbrinella
Artemesia frigida
Artemesia scopulorum
Astragalus alpinus
Cerastium beeringianum
Phlox pulvinata
Sedum lanceolatum
Sibbaldia procumbens

Grass/Grass like

Agropyron caninum
Agropyron scriberni
Calamagrostis purpurascens
Carex atrata
Carex phaeocephala
Deschampsia cespitosa
Festuca idahoensis
Juncus drummondii
Koeleria cristata
Luzula spicata
Leucopoa kingii
Phleum alpinum
Poa alpina
Poa secunda
Poa sp
Trisetum spicatum

Trees/Shrubs

Pinus albicaulis
Ribes sp.

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