PLANT MATERIALS FOR USE ON DISTURBED ALPINE AREAS IN MONTANA

by

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ABSTRACT

Disturbances in the alpine zone result from many causes, but the number of humans using these areas have had the greatest impact in recent years. Modern technological advances and sociological pressures are increasing demands for the utilization of this zone. Consequently, disturbance-causing activities are accelerating at a rate that may exceed our ability to develop the appropriate techniques to adequately ameliorate such disturbances.

Controlling soil erosion on a disturbance by establishing vegetation is a primary requirement of successful reclamation. The edaphic, physiographic and climatic barriers to successful revegetation of the alpine zone are generally understood. In addition, a considerable amount of information has accumulated on the plant establishment or revegetation phase of reclamation for these areas. Unfortunately, this information consists mainly of scattered research reports and operational experience. Throughout all of these reports, the main problem underlying the plant establishment phase of alpine reclamation is the lack of adapted plant materials. Most commercially available species are not adapted to the harsh environmental conditions of this region.

The increasing demand for plant materials for the revegetation of alpine disturbances has created the need to select adapted materials and efficient seeding techniques to ensure their survival. This will require the selection of native or introduced plant species of the appropriate ecotypes and their propagation, probably at low elevations, for seed harvesting. These plant species should be tolerant of wind, cold, long snow cover, short growing seasons, and drought. Seeding techniques must insure that the seed remains on site despite a very coarse material that hinders seed bed preparation and high velocity winds for prolonged periods. This paper reviews the current status of our knowledge and our limitations with respect to the revegetation of alpine areas in Montana.

INTRODUCTION

The alpine zone in Montana is an important recreational area, a vast reserve of mineral resources, and summer wildlife habitat. However, this zone probably serves its most vital role as the primary watershed of urban and agricultural communities.

The alpine zone referred to in this paper pertains to that portion of the landscape above the upper limit of tree growth in the higher mountain regions of the western one-third of the state. This mountainous region is collectively referred to as the Northern Rocky Mountains. In Montana alone, at least 25 separate mountain ranges contain alpine areas (Arno and Hammerly 1984). The zone is characterized by short growing seasons, long cold winters, and high winds. The vegetation is characteristically dominated by low-growing native perennial graminoids, forbs and dwarf shrubs.

Plants in alpine ecosystems are well adapted to the extreme physical environment. However, because alpine ecosystems evolved over millions of years in the absence of humans, these areas are sensitive to disturbances by people. A survey of land management agencies was conducted in 1976 to determine the nature and extent of alpine disturbance in the western United States (Brown et al. 1978b). Results of this survey indicated that of the 7.2 million acres of alpine tundra in the western U.S. (exclusive of Alaska), nearly 12 percent had been disturbed and, in the opinion of the major land management agencies, is in need of rehabilitation. Pressures from such activities as mineral exploration, water harvesting and

recreation are increasing. The results of this survey indicated an anticipated additional disturbance of 35,611 acres per year (Johnston and Brown 1979).

Alpine ecosystems are environmentally unique, and require special management and reclamation techniques. This "uniqueness" coupled with the fact that resource managers responsible for these areas are not specifically trained in alpine ecology, indicates that revegetation of alpine lands will become increasingly important in the near future. Programs geared towards alpine revegetation and in particular plant materials development for alpine areas require immediate attention. Most available plant materials have been bred and selected for more temperate environments, consequently, they are not adapted to the rigors of the alpine ecosystem.

The purpose of this paper is to consolidate and present information pertaining to the problems associated with the revegetation of the alpine zone in Montana. Its second aim is to present ecological evidence in favor of utilizing adapted plant materials for use in this unique environment.

THE ALPINE ECOSYSTEM

Nature and Extent

Timberline, which defines the lower limit of the alpine zone, is that elevation above which erect trees do not normally grow. This ecotone between alpine and forest is seldom sharp; it is often characterized by alternating patches of trees and herbaceous plants.

Because the alpine zone is present only on mountains, much of the landscape has varied relief with rocky, snowcapped peaks. However, there are also large areas of gently rolling to almost flat topography. The nature of any area depends on the degree and type of glaciation. Valley glaciers have been a major factor in the formation of the landscape of the rugged alpine regions, with cirques, hanging valleys and morainal deposits all common features (Thilenius 1975). These features are well represented in Glacier National Park along the western slope and continental divide. The flat to rolling terrain may be the result of leveling by frost action (cryoplanation) in areas which were unglaciated. The level to rolling alpine landscape is characteristic of the Absaroka Mountains/Beartooth Plateau region of southwestern Montana.

In the northern Rocky Mountains of Montana, the lower limit of the alpine zone varies from approximately 3,000 meters (10,000 feet) in the south (Gomm 1974) to 2,200 meters (7,000 feet) in the north (Choate and Habeck 1967). Figure 1 shows the general decrease in altitude of timberline in Montana as a function of latitude. The general decrease in the elevation of timberline with latitude is about 100 meters per degree north (Thilenius 1975). An eastward rise in the alpine

timberline zone is also noted (Figure 2). This rise results from the increasingly continental climate eastward, with diminished snowfall and warmer summers at any given elevation.

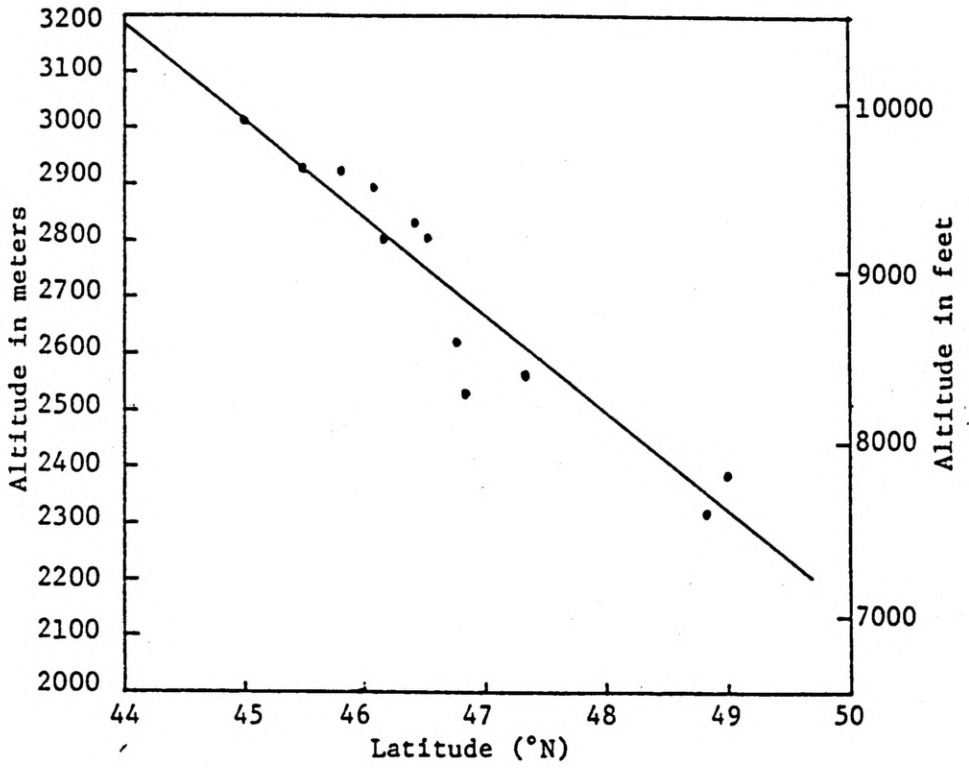


Figure 1. The altitude of timberline for 12 alpine areas in Montana as a function of latitude (Bamberg and Major 1968).

Most of the alpine zone is Federal land and comprises a significant proportion of land within wilderness areas. This area is under the jurisdiction of agencies of either the U.S. Department of Agriculture (Forest Service) or the Department of the Interior (Bureau of Land Management, Bureau of Indian Affairs, or National Park Service). The conterminous United States contain approximately 2,915,991 hectares (7,205,315 acres) or 29,158 square kilometers (11,258 square miles) of

alpine lands (Johnston and Brown 1979). The alpine zone of Montana is primarily located in the southwestern portion of the state, but it is also found on isolated mountain peaks throughout the western one-third of the state. It comprises approximately 233,428 hectares (576,800 acres) or 2,331 square kilometers (900 square miles) (Gomm 1974).

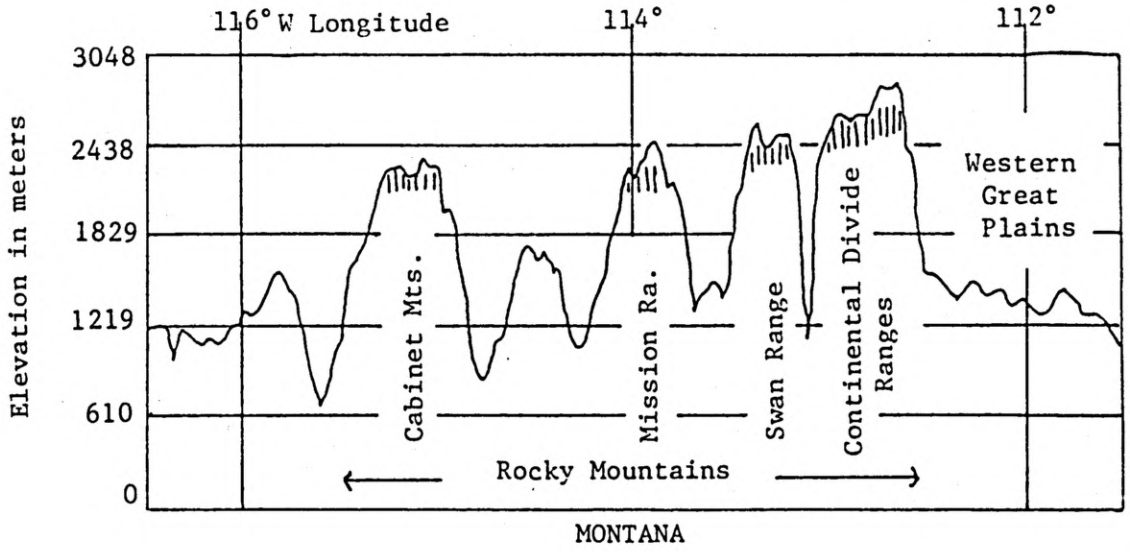


Figure 2. A west-to-east cross-section of Montana at 47 1/2°N latitude, showing the eastward rise in the alpine timberline zone (Arno and Hammerly 1984).

Arno and Hammerly (1984) divided the Northern Rocky Mountains of Montana into four geographic regions based on climatic influences; the Northern and Southern Continental Ranges, the Intermountain Ranges and the Inland-Maritime Ranges. The western and northern portions of the Northern Rockies are more moist as a result of the oceanic influence on the climate. Conversely, the southern and eastern portions of the Northern Rockies have drier, more continental climates.

Classification

The alpine zone provides summer forage for many kinds of wildlife, and its mining and recreational uses have increased. Management and planning become more important for these regions as demands for their use grow. The classification of vegetation and soils is essential for proper, long-term management as it provides a framework for land use and reclamation planning.

Due to the variation in microhabitat and the wide ecological amplitude of alpine species, designation of communities on the basis of species composition or productivity is difficult. Payne (1973) briefly described the alpine zone of the Absaroka/Beartooth complex in regards to utilization by domestic livestock. Ross and Hunter (1976) broadly categorized the alpine zone based on average annual precipitation, similiarity of soils and corresponding natural plant communities.

Habitat type classifications have been developed for the forests, grasslands and shrublands of the mountainous one-third of Montana (Mueggler and Stewart 1978, Pfister et al. 1977), and the wetlands in the valleys and plateaus of central Yellowstone National Park (Mattson 1984). Descriptions cover natural grassland, shrubland and forest vegetation within the lower intermountain valleys, the foothills and the subalpine regions. Unfortunately, the alpine zone is not covered by these classification systems.

Characterization of the Environment

The soils of the alpine region are a complex mosaic. Superimposed on the soil mantle is an equally complex mosaic of vegetation,

which varies greatly in its floristic composition and productivity. Alpine environments are among the most rigorous on earth, with extreme variability in almost all aspects being a major difference from lower elevations. In an alpine environment the physical factors almost always control the growth and distribution of biological populations and communities. Therefore the following discussion directly relates to the factors limiting alpine revegetation whether through natural processes or initiated by management practices.

Climatic

The alpine climate can be viewed in terms of gradients. Billings (1979) proposed three which account for climatic variations within regional and local alpine areas; macrogradients, mesogradients and microgradients. Macrogradients are latitudinal or elevational. Mesogradients result from local topography and are the major environmental influence on an area with respect to snow accumulation and melting, as well as plant species composition and production. Figure 3 illustrates a typical alpine mesogradient. Microgradients are usually the result of small elongated snowdrifts in the lee of some form of obstruction.

The overriding environmental attribute of the alpine zone is cold temperature. Temperatures may vary greatly on a daily basis and can fall below 0 C during the growing season, thus retarding photosynthesis, nutrient and water uptake, and phenological development. Low temperature may damage meristematic tissues of all but the most cold-hardy plant species (Brown et al. 1978b). Freezing temperatures can

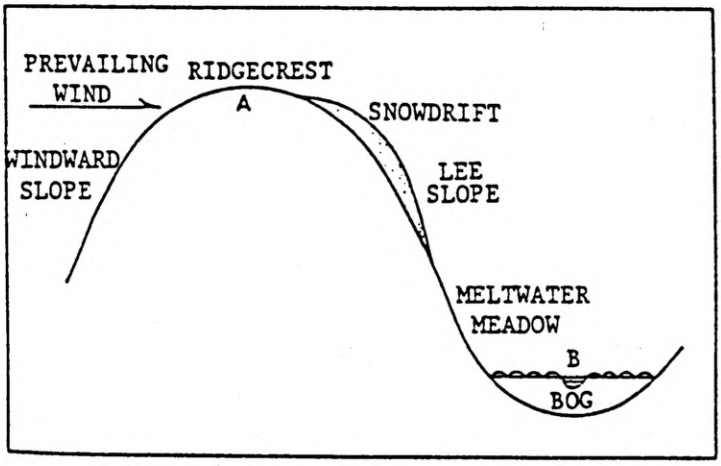


Figure 3. Diagram of a typical alpine mesotopographic unit with its environmental gradient from the upper windward slope to the small leeward valley. The scale is from 50 meters (160 feet) to 1,000 meters (3,280 feet) from A to B (Billings 1973).

also cause soil frost-heaving and needle-ice formation, damaging young seedlings.

The major portion of alpine precipitation is deposited in the form of snow. Rainfall events during the growing season are infrequent and have little effect on the growth rate of alpine species. They often come as high-intensity storms with consequent high runoff and lack of penetration into the root zone. Only about 10% of the annual precipitation is received during the growing season on the Beartooth Plateau (Brown et al. 1978b). Gauges have been installed by the Soil Conservation Service throughout the mountainous regions of the state to improve the accuracy of water supply forecasts. Table 1 shows data from gauges at SNOTEL (Snow Survey Telemetry) sites at selected alpine or near-alpine locations in Montana (see Figure 4 for approximate locations). These data reveal that total snow and rainfall vary widely in space and time.

Table 1. Twenty year precipitation averages (1961-1980) for selected alpine or near-alpine SNOTEL sites in Montana from USDA-SCS Snow Survey (Farnes 1985).

Snotel Site	Mountain Range	Elev. (m)	Precipitation (cm) Mean Annual	High	Low
1 Fisher Creek	Beartooth Plateau	3300	156	203	119
2 Carrot Basin	Madison Range	3000	134	145	117
3 Spur Park	Little Belts	2700	102	135	76
4 Rocker Peak	Highland Mountains	2670	79	107	53
5 Barker Lakes	Anaconda-Pintlars	2750	90	122	74
6 Twin Lakes	Bitterroot Range	2130	171	216	114
7 Hoodoo Basin	Bitterroot Range	2170	185	196	168
8 Badger Pass	Front Range	2300	158	191	122
9 Flattop	Glacier Nat. Park	2100	216	239	145

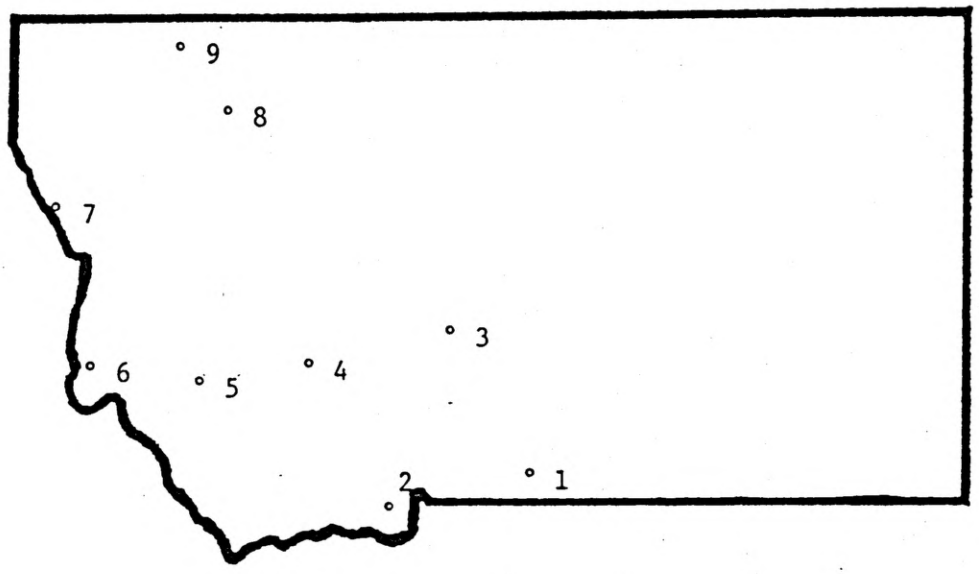


Figure 4. Approximate location of selected alpine and near-alpine SNOTEL sites in Montana.

The alpine zone is usually windy, with average wind-speeds of 40-50 km/hr common during the winter (Thilenius 1975). Prolonged high winds often result in severe desiccation of exposed plant parts during both winter and summer seasons (Johnston et al. 1975). Wind maintains snow-free areas on ridges and slopes, exposing them to severe frost damage and desication. The wind blows snow onto lee slopes, shortening the growing season there and resulting in abrasive damage to exposed plants on windward slopes. It also erodes fine soil particles from disturbed sites, reducing water- and nutrient-holding capacities (Brown et al. 1978b).

Solar radiation affects soil and air temperatures, humidity, soil moisture and energy flow within the alpine ecosystem. High radiation loads in the alpine result in high soil and plant surface temperatures and promote summer drought and high evaporation (Brown et al. 1978b).

Edaphic

Broadly defined, an edaphic factor is a condition or characteristic (physical, chemical or biological) of the soil or other substrate that influences organisms, macro or micro, plant or animal (Everett 1980).

The alpine soils of Montana have received little attention from soil scientists because they are of limited extent, not arable and generally inaccessible. Notable exceptions are studies of the vegetation and soils of the Beartooth Plateau by Johnson and Billings (1962) and Nimlos and McConnell (1962). Additional studies of three alpine regions with calcareous parent materials; the Big Snowy Mountains, the Flint Creek Mountains and in Glacier National Park, by

Bamberg and Major (1968) must also be noted. Thilenius and Smith (1985) studied the alpine soils and vegetation of the Absaroka Range in northwestern Wyoming. In their investigation the alpine soils were represented by three soil orders: Entisols, Inceptisols and Mollisols.

Soil development is influenced by a number of factors including parent material, glaciation and other geomorphic processes, vegetation, biological activity and climate (Brown et al. 1978a). Topography, through its control of snow distribution is the most important factor in controlling the development and distribution of soils in the alpine zone (Burns 1980). Wind and water also contribute to soil development. Exposed crests and ridges often have a limited vegetative cover, allowing for the transport of fine soil particles by wind and water. Since the absence of plant development also influences soil development, soils underlying snowbanks are poorly developed and often low in humus. These soils exhibit low water-holding capacities which accentuate the drought-stress conditions when these sites are exposed (Thilenius 1975).

Cold temperatures and frozen soils inhibit the chemical reactions and biotic activity that contribute to soil genesis. The mean annual temperature of soils in the alpine zone of Montana has been estimated at about -1 C (Nimlos and McConnell 1962). The mean summer temperature has been reported to be about 7 C (Nimlos et al. 1965), much lower than soil temperatures below the tree line. Soils developing under such a regime are very young, heterogeneous, and poorly developed. In addition, alpine soils are generally thin and coarse-textured. The nutrient capital and exchange capacities of such

soils are also low (Brown et al. 1978b). Low fertility may result in part from the type of parent rock from which they are formed; soils from granites are inherently less fertile than those from volcanic rocks or limestone (Thilenius 1975). Low levels of nitrogen have been reported to limit alpine plant growth. The problem is not one of low total nitrogen content, because the surface horizons contain abundant nitrogen (ca. 20,000 to 40,000 kg/ha). Most of the nitrogen is in the organic form with less than 0.01 percent in the inorganic form as nitrate or ammonium, the form which is available to plants (Nimlos and McConnell 1965, Thilenius 1975). Apparently organic matter and nitrogen accumulate because the microbial oxidation of organic material is restricted. Smith (1966) also showed a deficiency of available phosphorus in two high altitude soils, probably resulting from the same causes that contributed to low inorganic nitrogen in alpine soils.

Soil reaction in the alpine zone is often strongly acidic due to the presence of only small quantities of basic cations (especially Ca and Mg) in the parent material, combined with slow rates of weathering and release of cations. Important exceptions to this include soils derived from basic materials such as basalt, volcanic debris and sedimentary rocks (Retzer 1974).

Physiographic

Massive mountain building and erosional processes, altered by glaciation, are largely responsible for alpine landscapes. Dominant rock types in the Rocky Mountains are granites, quartzites, and pegmatites; massive basalts and other volcanic rocks occur

sporadically. The sedimentary materials have largely been eroded, but remnants can still be found in some locations.

Topographic features influence climatic factors, especially in terms of moisture and temperature. North-facing slopes have typically cooler diurnal air and soil temperatures than do south-facing slopes, resulting in a lesser degree of soil development and different vegetative composition and production.

Many alpine species are restricted to snowbank areas because of the protection provided by the banks against winter desiccation, low temperatures and summer drought (Billings and Bliss 1959, Billings 1979). However, where snow covers the ground until mid or late summer, it can critically shorten the growing season. The presence or absence of particular species, therefore, appears frequently to be a matter of enough but not too much snow cover.

The most important factor controlling the distribution and growth of alpine plants is soil moisture (Billings and Mooney 1968). Soil moisture, in turn, depends to a large extent on the drift patterns of snow that result from the interaction between wind and topography (Thilenius 1975). The combined influence of these factors and the resulting moisture gradient controls the structure, composition and pattern of alpine communities. Figure 5 shows alpine vegetation types as related to topography, wind and snow cover.

Soil formation goes hand-in-hand with succession of plants and the development of a vegetative community. Alpine soils, once formed, are protected by the native vegetation; and the vegetation, in turn,

is dependent upon these soils for water, nutrients, and persistance (Billings 1979, Eddleman 1984).

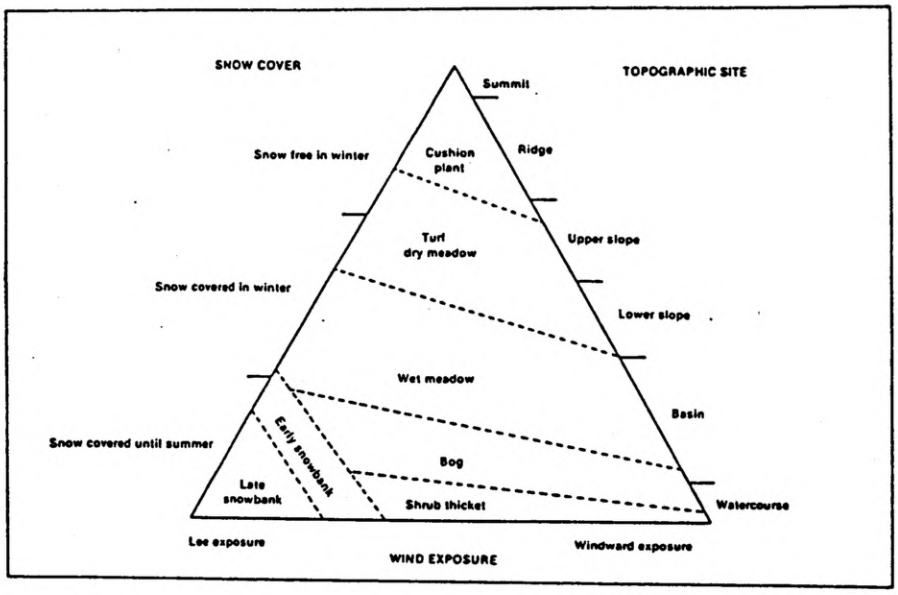


Figure 5. Alpine vegetation as related to topography, wind, and snow cover (Johnson and Billings 1962).

Floristic

The vegetation and environment of the alpine zone in Montana is similar to that of the arctic, however, there are significant differences. The alpine vegetation in Montana is not commonly underlain by permafrost, the topography is generally rougher, and much of the land is better drained. The growing season is longer, but the days are shorter in the alpine zone. The alpine regions are floristically richer and more diverse even though many of the same plant species occur in both alpine and arctic floras. The alpine flora is species poor, however, when compared to floras of lower

elevations. The differences between common arctic and alpine species becomes progressively greater southward. Consider the 210 plant species found in the Beartooth Range of Montana, 47 percent of them occur in the arctic as well (Johnson and Billings 1962). Whereas, 150 km south in the Teton Range of Wyoming, only 25.9 percent of the 216 plant species have arctic affinities (Spence and Shaw 1981).

Adaptive Strategies of Alpine Plants

The key to successful survival in alpine environments is the development and operation of a metabolic system which can efficiently capture, store and utilize energy at low temperatures and in a short period of time. The major adaptations of vascular plants to the alpine environment in addition to these physiological adaptations are reduction in height, perennial life cycle and herbaceous habit, regardless of the plant's taxonomy.

Growth and Life Forms

Perennials dominate alpine landscapes as short growing seasons and cool temperatures often preclude annual seed production. They have the ability to save energy in that leaves, flowers, and fruit do not have to be developed each season. The life form distribution in some alpine areas of Montana are summarized in Table 2.

The perennial herbs are of four principal growth forms; grass-like plants, cushion plants, rosette plants, and leafy-stemmed plants (Billings and Mooney 1968). Billings (1979) categorized alpine growth forms in order of prevalence, with distribution of each type determined primarily by water availability and growing season lengths:

1. Grass-form plants dominate more mesic alpine areas and possess morphological features such as narrow leaves and stems to decrease wind damage.

2. Cushion plants are present on drier, exposed areas where windy conditions are prevalent. These plants maximize exposed leaf surface area for high photosynthetic activity, yet have minimal exposure to environmental conditions. Temperatures within the cushion plant canopy may be several degrees higher than external temperatures, and the outer edge of the plant serves to decrease wind velocities and reduce dessication. Deep primary root systems are common for anchoring and water uptake, with shoots proliferating near the soil surface (Daubenmire 1941).

3. Rosette plants are adapted to windswept areas of alpine locations. Growth is close to the soil surface where air temperatures are higher. Stems are short with little vertical separation, resulting in reduced exposure to cold temperatures, wind damage and dessication.

4. Leafy-stemmed perennial forbs are present on mesic and also drier sites where conditions permit.

Other growth forms of importance include dwarf coniferous or deciduous shrubs, lichens and mosses. The shrub life form, however, is not especially common in the alpine zone. Lichens and some mosses occur beyond the environmental limits of vascular plants. Apparently, lichens can withstand environments with lower growing season

temperatures than vascular plants, providing there is a supply of surface water at some time during the year (Billings and Mooney 1968).

Table 2. Life form distribution in alpine vegetation studies of Montana mountain ranges (Jackson 1985).

Locality	# Species Sampled	Annual%	Ephemeral Perennial%	Persistant Perennial%	Reference
Beartooth Plateau	210	0.5	1.9	97.6	Johnson & Billings 1962
Glacier Nat. Park	187	0.5	2.1	97.3	Bamberg & Major 1968
Flint Creek Mountains	169	1.1	3.0	95.9	Bamberg & Major 1968
Big Snowy Mountains	104	0.9	4.8	94.3	Bamberg & Major 1968

Reproduction

Most alpine plants reproduce by seed rather than vegetatively, with the principal cross-pollinated plants being pollinated by insects and wind. Reproduction by seeds appears to be most common and most important in drier alpine sites, although layering is common in cushion plants. Vegetative reproduction by rhizomes or runners is more common in wet or moist meadows. Some alpine species reproduce by apomixis (asexual seed production) and vivipary (germination of a propagule while attached to the parent plant) (Billings and Mooney 1968).

Flower buds are normally preformed during the previous year or two years prior to bud emergence. This adaptation allows them to complete flowering in a very short growing season. Cold growing-

season temperatures inhibit flowering and fruiting in many years. In warmer years seed production is abundant.

Seed Physiology

Almost all seed germination in alpine locations takes place in early summer after snowmelt following a year of seed production. Most species lack seed dormancy and the elapsed year (or more) between seed production and germination is environmentally imposed. There are a few species which have seed dormancy of one type or another. Seed dormancy is often caused by a hard and impermeable seed coat, and can be overcome by scarification, stratification, light or elapsed time (Billings and Mooney 1968).

Optimum germination temperatures are 20 to 30 C, although alternating temperatures appear to bring about higher germination success. Dormancy does not seem to be an attribute of alpine plant seeds, but they will not germinate and remain viable for long periods if exposed to low temperatures (Billings and Mooney 1968).

Plant Physiology

Plant dormancy may be broken any time from April to September. The important factors are snow melt, increase of soil and air temperatures to about 0 C, and the presence of water. A relatively long photoperiod may also be important, but photoperiod has no effect without temperatures above 0 C (Bliss 1962).

Seedling development is devoted primarily to root growth. This growth is important to survival since the surface soil may become very dry in late summer. The root portions of most alpine dicots have much

greater biomass than the shoots (2-6 times greater) and act as carbohydrate storage organs. However, grasses and sedges have smaller root:shoot ratios (Billings 1974b).

Alpine plants have evolved a metabolic mechanism that allows them to capture, store and utilize energy at temperatures close to freezing during a 6 to 10 week growing season. Some vascular alpine plants photosynthesize at temperatures as low as -6 C, while lichens may photosynthesize at -24 C (Bliss 1962). Alpine ecotypes apparently have less chlorophyll than lowland ecotypes at the same latitude. The lower chlorophyll content of alpine ecotypes causes greater reflectance and may be involved in the heat balance of the leaf (Billings and Mooney 1968).

Phytosociology

Alpine vegetation in Northern hemisphere mountains, is regarded as a complex mosaic of communities arrangeable into types or along vegetational gradients (Billings 1973). Topographic site, degree and duration of winter snow cover, and wind exposure are the major influences (Figure 5). The combined influence of these major factors of the alpine environment is basically a gradient of available moisture, which generally controls the structure, composition and pattern of alpine communities.

While the species composition of alpine communities may be highly variable, the physiognomy of alpine communities reflects its environment. Thus, the general trend from a cushion plant community on exposed rocky ridges, to turfs, to wet meadows, bogs and shrub thickets is commonly repeated in most alpine locations (Thilenius 1975).

Competition and Succession

Competition among species appears to be less intense in alpine plants than in those of lower elevations (Thilenius 1975). Individual alpine plants have only a very local effect on their environment. The generally scattered distribution of alpine plants may account for this characteristic. Forcella and Harvey (1983) found that the high altitude zone in Montana is essentually weed-free with or without disturbance. Eurasian weeds as a group seem unable to tolerate the cool and moist to very dry conditions of high altitude environments whether the site is shaded or light-saturated. Thus, the major responses of alpine plants are to environment rather than biological influences.

Choate and Habeck (1967), and Johnson and Billings (1962) stated that the concepts of climax and succession as developed in temperate, low-elevation regions do not appear to be applicable in the alpine zone. Chambers et al. (1984) concluded that succession in alpine ecosystems follows the same processes as those observed in more temperate ecosystems, only the changes in species and life form are less apparent. In alpine succession, early colonizing species are also members of the climax community (Chambers et al. 1984). Intense cryopedogenic action creates a dynamic instability in both vegetation and soils. Nevertheless, in areas where relatively constant environmental gradients exist for a long time, a steady-state community pattern can evolve which may be analogous to the climax community of lower elevations.

ADAPTED PLANT MATERIALS

The general principles of revegetation apply in any environment. However, Brown and Johnston (1979) state that aspects of timing, selection of adapted species and ecotypes, and microenvironmental considerations are of particular importance in the alpine zone because of the extreme environmental conditions.

Causes of Disturbance

The restoration of alpine disturbances requires considerable effort and assistance. The best management is protection of the resource before damage exceeds what is naturally repairable. Unfortunately, many alpine areas are currently threatened with severe disruption. Esthetic, wildlife and watershed values have been seriously damaged in some areas. The nature and extent of alpine disturbances in the western U.S. as of 1976 are summarized in Table 3.

Soil disturbance is the most characteristic feature of the alpine environment (Amen 1966). Commonly occurring disturbances in alpine areas result from cryopedogenic movement and frost heaves with soil lost through wind and water erosion. Soil disturbance continuously occurs in nature on a small scale, but the systems recover. Pocket gophers, for instance, are a major erosive agent on the alpine tundra. However, it is necessary to be able to distinguish natural erosion features from man-caused deterioration. Figure 6 shows the zones of stability on a theoretical alpine slope. The most stable soils are found in the zone of minimal snow cover.

Table 3. Summary of the nature and extent of alpine disturbances in the western U.S. as of 1976 (Johnston and Brown 1979).

Nature of Disturbance	Extent of Disturbance Acre	Hactare	Percent of Total Disturbance
Grazing	633,056	256,194	74.5
Recreation	94,244	38,140	11.1
Mining	85,686	34,677	10.1
Roads	31,499	12,748	3.7
Pipelines	1,689	683	0.2
Powerlines	714	289	0.1
Reservoirs	676	274	0.1
Other	1,964	795	0.2
Total Disturbance	849,528	343,800	100.0
Total Alpine Area	7,205,315	2,915,951	
Percent Disturbed	11.8	11.8	
Additional Anticipated Disturbance by 1980 *	142,444	57,646	16.7

*Based on 1976 total

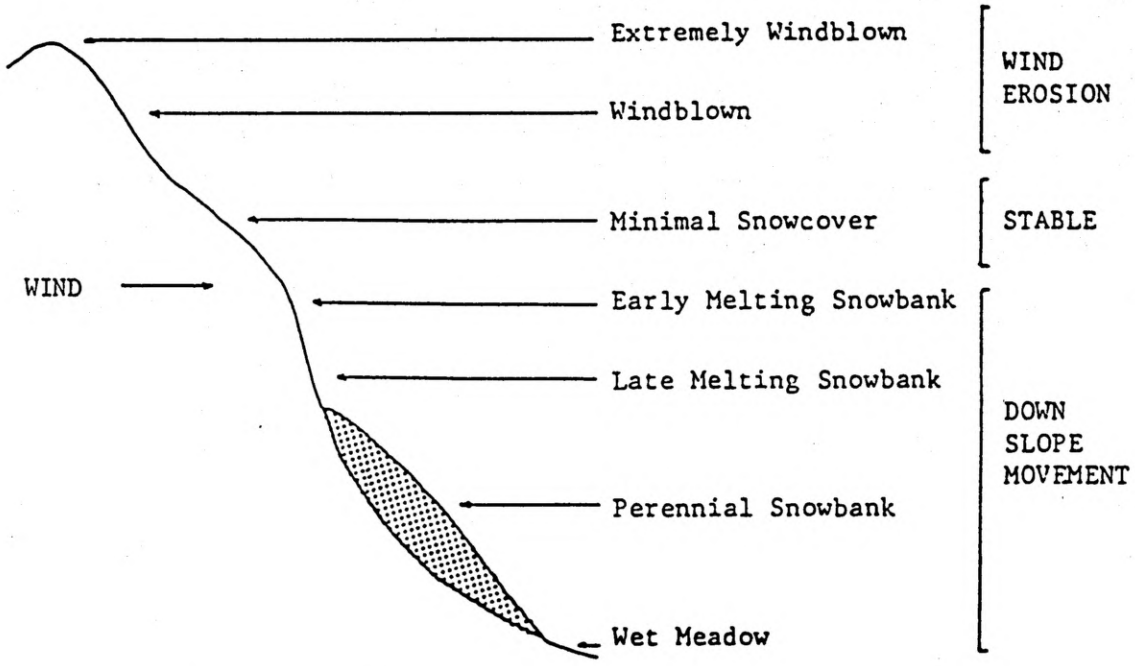


Figure 6. Zones of stability on the theoretical alpine slope (Burns 1980).

An alpine disturbance removes the A horizon. It is in this layer that most of the nutrients, the fine particles from the loess, and the higher pH so beneficial to proper vegetation growth are located (Burns 1980). Willard (1976) estimated that it takes 500 to 1000 years to build an inch of topsoil in the alpine zone. Willard and Marr (1971) indicated that it will take at least several hundred and possibly even a thousand years for ecological processes to produce a persistant ecosystem in some areas modified by visitor activities.

Disturbances in alpine regions result from many causes, but mining activities have probably had the most devastating impacts. Disturbances from mineral exploration and mining have a long history in Montana alpine. Such activities began on the Beartooth Plateau in the late 1870's (Johnston et al. 1975). Many mining related disturbances, such as drilling pads used for mineral exploration, spur roads, and trenches are relatively small, usually occupying less than 1 hactare (2.5 acres). However, severe mining disturbances result in the total loss of soil and exposure of acid-producing pyrites with toxic concentrations of metals.

The primary consideration in relation to soil is its stability. Plants cannot be established if the substrate is constantly moving or eroding. Greller (1974) stated that stabilization, increased soil moisture, and increased organic matter greatly facilitated colonization of denuded sites.

Research Projects

Research on the revegetation of alpine areas is relatively new with considerable work being carried out the past ten to fifteen years. The majority of well-designed studies have originated in the past five to ten years. Most of this research has been done in the western United States and Alberta, Canada (Sims et al. 1984).

One of the earliest documented alpine seeding and transplanting projects was conducted by Harrington (1946) in Colorado. A number of recent studies have examined the performance of plant species at alpine or near-alpine sites with variation in their design and emphasis depending upon the land use. Considerable attention has been focused on mining reclamation (Brown and Johnston 1976, Brown et al. 1976, Brown, Johnston, and Jackson 1978a, Jackson 1982), range restoration (Brown and Johnston 1979, Gates 1962, Plummer et al. 1968, Smith and Alley 1966, Thilenius et al. 1974), grazing influence on vegetation (Bonham 1972, Stasia et al. 1970), digestibility and chemical composition of vegetation (Johnston et al. 1968, Smith 1969), ski slope revegetation (Behan 1983, Hall 1982, Walker 1982), and revegetation after road construction (Williams et al. 1984). Hartley (1976), and Willard and Marr (1970 and 1971) investigated the effects of recreational impacts on alpine and subalpine vegetation in National Parks. Belsky (1975) described vegetational damage caused by a spill of diesel fuel into an alpine meadow. Successful sod transplantings have been reported from alpine areas in California (Sorensen 1985), Washington (Miller and Miller 1976) and Alberta (Harrison 1985).

One of the major problems associated with revegetating alpine disturbances is the selection of adapted plant species. Historically, most revegetation research which evaluated species performance concentrated on identifying commercially available species adapted to high altitude sites (Berg 1974, Gomm 1962, Hull 1964, Kenny and Cuany 1978, Plummer et al. 1968). Many native plant species that appear to be adapted to alpine disturbances have been identified (Brown et al. 1978a, 1978b, Brown and Johnston 1978, 1979, Etra et al. 1984, Greller 1974, Guillaume 1984, Harrington 1946, Willard and Marr 1970 and 1971, Ziemkiewicz 1985a).

Although several of these studies had included native species, introduced species predominated because of their commercial availability. Takyi and Islam (1985) concluded that the use of faster-growing cultivated species as companion crops to the native grasses had positive results. The companion crops proved to be of little benefit to the successful establishment of native grass cover in early stages, but stablized the ground surface. The companion crops did not appear to influence the relative presence or distribution of natives in the established plant cover after 2 years.

Grasses have been the major plant group seeded on alpine soils, but various introduced legumes have also been evaluated because of their forage quality and ability to fix nitrogen (Johnson and Rumbaugh 1985, Takyi and Islam 1985, Townsend 1962). The use of legumes may result in an increase of the often limiting level of plant available nitrogen (Faust and Nimlos 1968). Several alpine forbs and legumes

are considered useful for revegetation but to date research has been limited (Sims et al. 1984).

Species Evaluations

Ziemkiewicz (1985a) evaluated selected lines of nine native and four commercially available introduced grass species at an alpine site. The results indicated that the introduced and native grasses generated similar cover levels though the native grasses had a greater reproductive potential. Based on cover development and reproductive potential the natives; Poa interior[1], Festuca saximontana, Agropyron latiglume and the introduced grass Festuca rubra were recommended for alpine revegetation.

Chambers et al. (1984) studied plant succession on four unreclaimed alpine disturbances on the Beartooth Plateau. Several naturally colonizing species were identified. Those considered potentially useful for revegetation included: Carex paysonis, Deschampsia cespitosa, Sibbaldia procumbens, Trisetum spicatum, Polygonum bistortoides, Potentilla diversifolia, Geum rossii, and Artemisia scopulorum. Species considered excellent for revegetation of alpine disturbances in the Beartooth Mountains by Brown and Johnston (1976, 1978) included: Deschampsia cespitosa, Poa alpina, Phleum alpinum, Agropyron trachycaulum, and Trisetum spicatum. Plants which have been successful in the early stages of revegetating alpine disturbances are shown in Table 4.

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1. Refer to Appendix for the complete scientific nomenclature, common names and recommended names use throughout the text.

Table 4. Vascular plant species found successful for rehabilitation of alpine disturbances by either colonization observations, seeding, or transplanting studies (Brown et al. 1978a).

Species	Seeding	Transplanting	Colonization
GRAMINOIDS			
Agropyron latiglume	X		
A. scribneri	X	X	X
A. trachycaulum	X	X	
Agrostis scabra	X		
Alopecurus pratensis *	X		
Carex lenticularis			
C. nigricans		X	X
Deschampsia caespitosa	X	X	X
Luzula spicata		X	X
Phleum alpinum	X	X	X
Poa alpina	X	X	X
Trisetum spicatum	X	X	X
FORBS			
Achillea millefolium	X		X
Antennaria lanata		X	X
Arenaria fendleri			X
A. obtusiloba			X
Epilobium alpinum			X
E. angustifolium			X
Erysimum nivale			X
Lupinus argenteus		X	X
Mertensia viridis		X	X
Phacelia sericea	X	X	X
Sedum lanceolatum			X
Sibbaldia procumbens		X	X
Silene acaulis			X
Thermopsis divaricarpa	X		
Trifolium dasyphyllum	X		X
T. nanum			X
Vicia americana	X		
WOODY SPECIES			
Cassiope mertensiana			X
Juniperus communis			X
Phyllodoce empetriformis		X	X
Salix nivalis		X	X
Tsuga mertensiana			X

*Introduced species

Of the ski areas of Montana with the highest elevations (subalpine), least favorable aspect, and least fertile soils, the species that were most abundant were Bromus inermis, Phleum pratense, Festuca rubra, and F. ovina. The forb, Trifolium repens was noted at the higher elevations (Behan 1983).

Ziemkiewicz (1985b) developed a quick methodology to assess significant site conditions and tailor field staff revegetation treatments to meet site specific requirements. Species recommended for revegetating alpine areas in Alberta are listed in Table 5. The recommendations were based on nine factors determining species success or failure and the use of a combination of the 15 grasses and 8 legumes which were used most extensively in North America. These recommendations

Table 5. Introduced grasses and legumes recommended for revegetating alpine areas in Alberta.*

Site Characteristics	Species Success Factors	Recommendations
Alpine, heavy soil, sloped, poor drainage	Nutrient deficiency tolerance, Grazing resistance, High-elevation tolerance, Flooding tolerance, Erosion control	Alopecurus pratensis Agrostis stolonifera Trifolium hybridum T. repens
Alpine, acid soil	Nutrient deficiency tolerance, Grazing resistance, Fire resistance, High-elevation tolerance, Acid tolerance	Poa compressa Festuca rubra Agrostis stolonifera Trifolium hybridum T. repens
Alpine, gravelly soil, sloped	Drought tolerance, Nutrient deficiency tolerance, Grazing resistance, High-elevation tolerance, Erosion control	Poa compressa Alopecurus pratensis Festuca rubra Medicago sativa Trifolium hybridum

* Based on species adaptability to specific site parameters (developed from Ziemkiewicz 1985a).

were based solely on the author's personal opinion. It is interesting to note that in the Manual of Species Suitability for Reclamation in Alberta (Watson et al. 1980) Poa compressa is rated as not suitable for alpine areas in Alberta due to variable reclamation success in this zone.

Etra et al. (1984) and Guillaume (1984) examined the performance of selected grass and legume strains at various subalpine and alpine test plots in Colorado. Most of the species tested were not native but, they appeared adapted to subalpine conditions. The authors state that this may not be true at higher elevations where native species may be most appropriate for revegetation. The authors' research indicated that the native species showing the greatest promise for revegetation of alpine areas in Montana included:

Agropyron latiglume
Agropyron scribneri
Androsace septentrionalis
Carex sp.
Cirsium sp.
Deschampsia cespitosa
Geum rossii
Mertensia viridis
Phleum alpinum
Poa alpina
Polemonium viscosum
Potentilla diversifolia
Rumex sp.
Senecio sp.
Trisetum spicatum

Presently there are no commercially available cultivars of native alpine ecotypes. Deschampsia cespitosa is in production at the Forestry Science Laboratory of the USDA at Utah State University, Logan, Utah. Deschampsia cespitosa, Phleum alpinum and Potentilla diversifolia are being evaluated at the Environmental Plant Center, Meeker, Colorado. Poa interior, Festuca saximontana and Trisetum

spicatum are currently being intensively studied for high elevation revegetation in Alberta (Sims et al. 1984).

Table 6 summarizes the grass species that various authors indicated as having the most potential for revegetation of alpine or near-alpine disturbances.

Table 6. Some grass species having potential for revegetation of alpine or near-alpine area disturbances.*

Scientific Name	Reference						
	1	2	3	4	5	6	7
Agropyron latiglume	+			+			+
A. subsecundum				+			
A. trachycaulum			+				
Agrostis alba			+			+	
Alopecurus arundinaceus					+		
A. pratensis						+	
Bromus inermis			+				
Dactylis glomerata						+	
Deschampsia cespitosa			+	+	+		+
Festuca ovina	+	+		+	+	+	
F. rubra	+	+			+	+	+
Koeleria cristata				+			
Phleum alpinum		+	+		+		+
P. pratense			+			+	
Poa alpina		+		+			+
P. compressa						+	
P. interior	+			+			
Stipa columbiana				+			
Trisetum spicatum			+	+			+

* Developed from results of performance and evaluation studies: 1. Ziemkiewicz 1985a, 2. Watson et al. 1980, 3. Upper Colorado Environmental Plant Material Center 1980, 4. Takyi and Islam 1985, 5. Hassell et al. 1983, 6. Ziemkiewicz 1985b, 7. Guillaume 1984).

Species Selection

The uniqueness of alpine species lies in the fact that they are the only plants adapted for metabolizing, growing and reproducing at low temperatures. The alpine tundra vegetation of North America consists of about 300 species (Billings 1973, 1974a), 10 percent of

which will establish and reproduce themselves on disturbed alpine sites (Brown et al. 1978b, Brown and Johnston 1978). However, Eaman (1974) states that nearly all native high altitude plants have potential for revegetating high altitude disturbed areas, because these plants meet one of the first requirements of any species to be used for revegetation; they are adapted for growth in the environment under consideration.

When selecting species for revegetation, attention should be directed toward species which are capable of long-term survival and reproduction in alpine ecosystems. Characteristics of species that are considered desirable for revegetation include: 1) large and/or more consistant seed production; 2) effective seed dissemination; 3) high germination percentages; and 4) large tolerance limits for seedling establishment on disturbed sites (Chambers et al. 1984).

Plant geneticists and breeders feel that improvements can be made in native plant populations similar to those made in agricultural plants. The intent is not to drastically alter the plants adaptive characters; but to improve seedling vigor, germination, persistance, reproduction and other desirable traits for rangeland uses. Generally, in revegetation the primary concerns are plant establishment and survival with minimum input (Kenny and Cuany 1978). Two features of alpine plants that deserve special attention are drought resistance and nitrogen fixation. Although large portions of the alpine zone have an abundance of water, many sites can develop moderate to relatively severe atmospheric and soil moisture stress levels during the growing season (Johnson 1980). Low soil water

potentials have been found in disturbed areas in the Beartooth Mountains by Brown et al. (1976) where potentials in the top 15 cm soil layer were lower than -20 bars.

Legumes differ from other plants in being able to convert nitrogen from the atmosphere into a form that is available for plant growth. In order to make use of the nitrogen in the air, legumes require the cooperation of certain bacteria. Bacteria of the genus Rhizobium penetrate the root hairs of legumes, then grow, multiply and stimulate the roots to produce small tubercles or nodules. It is in these nodules that free nitrogen is "fixed" into a usable form for plants. Although the bacteria associated with the various kinds of legumes are closely related, different types have become so adapted to certain species that they are unable to produce nodules on other species. Therefore, when a certain species is to be inoculated it is very important to use the right type of bacterial culture (Ashford and Heinrichs 1966).

Brown et al. (1976), and Berg and Barrau (1978) concluded that fertilizer application is essential for successful plant establishment on high altitude disturbances. Because of the increasing cost of nitrogen fertilizer and its application and the desire to restore disturbed areas to a self-sustaining state as rapidly as possible, providing nitrogen inputs through biological nitrogen fixation by legume-Rhizobium associations warrents further research (Johnson 1980). Studies in the Beartooth Mountains by Johnson (1980) and Johnson and Rumbaugh (1985) indicated that legumes native to high

elevation areas are capable of fixing significant amounts of nitrogen even on disturbed sites.

Native vs Introduced

Although species selection should ideally be linked to ecological principles, it is often tainted with human attributes such as relative "goodness or badness" that have little or no relationship to biological fact. In most cases, the more familiar introduced species have been selected for revegetation for three primary reasons: 1) their characteristics and responses are relatively well known; 2) through generations of selection and breeding, seed germination and plant vigor are more desirable; and 3) they are more readily available (Brown 1980).

Based on the available evidence, there appears to be no substantial difference between native and introduced species other than those that might be distinguished between any two species. It is adaptability vs. unadaptability that has far greater significance for revegetation than does the native vs. introduced distinction. Unfortunately, few species of either group are currently available for use in revegetating alpine sites.

Ecotypic Variation

Many plant species are able to withstand a wide range of environmental extremes by maintaining a high degree of genetic variability. However, ecotypes of a species respond differently when grown in an environment different from that in which they originally evolved. Ecotypic variation may be expressed in a number of

attributes, depending on their origin. Some examples are variations in winter hardiness, drought tolerance, and palatability.

Although one ecotype of a given species may do extremely well in one plant community or environment, another ecotype of the same species may be much better adapted to another environment (Plummer et al. 1968). Seeds from an ecologically different area than the site to be revegetated may be able to germinate, establish seedlings and grow vigorously, however, they may be less able to compete with other species, reproduce, or withstand certain soil or climatic extremes characteristic of the site. Ecotypic differences have been observed in northern versus southern populations or high altitude versus low altitude populations of several grass species (Mitchell 1978). Differences between edaphic ecotypes on different geologic substrata and drought stress ecotypes can also be considerable (Billings 1978). Therefore, ecotypes should be closely surveyed to ensure that seed of the most adapted population is used. When possible, seed and propagation material should be obtained from the problem area or from an area with similar climate and soil (Monsen 1975).

Native Seed and Propagation Material

An alternative to revegetating with introduced grasses and legumes is the use of seed or materials harvested from native stands. The best place to harvest suitable native plants is a similar disturbed habitat which has been revegetated (Kenny and Cuany 1978). Miller and Miller (1976) found that the propagation of plant material at lower elevations for replanting at disturbed alpine sites in the Washington Cascades was successful. Because of their rapid growth and

resistance to trampling, Carex nigricans, Luetkea pectinata and Sibbaldia procumbens preformed best.

Unfortunately, the disadvantages of native seed collecting generally out number the advantages. The main reason being that even in relatively good years the amount of viable seed produced may be low and the proper time to collect seed may be difficult to determine. Collection of immature seed results in low seed viability. Delaying collection may result in seed dormancy and loss of seed because fruits of many native plants dehisce rapidly. Collecting seeds from the ground may be possible, but usually results in low quality seeds and excessive cleaning costs (Young et al. 1983). Many native species have indeterminate type inflorescences where flowering and maturity are continuous for extended periods, it is difficult to avoid collecting immature seeds in this situation.

In agriculture, many of the undesirable plants are removed from a field before the seed crop is harvested. Good weed control practices minimize weed contaminant problems. In collecting seeds of native species, seldom can agronomic practices be applied to the stand producing the seed. Lastly, collection methods are largely hand methods because the desired native species do not grow in pure stands, and topography often limits use of mechanical equipment. When seed is not going to be offered for sale, cleaning is usually unnecessary. Direct reseeding with uncleaned seed has advantages in terms of handling, it provides a natural mulch which will help to retain moisture and hold the seed in place until germination (Milstein and Milstein 1976).

Vegetative propagation may be the best way to obtain quality planting stock for a given genetic trait. For some species, vegetative propagation is fast, simple and space efficient. Vegetative propagation may also be useful for producing individuals of those plant species that have seeds that are difficult to germinate. Transplanting natural tundra turf from a similar site, is the most successful technique for restoring damaged sites (Stevens 1976). However, there is usually not a source of tundra turf for transplanting without damaging other areas.

CONCLUSIONS

Potential plants for revegetation in the alpine zone, must be: 1) perennial, 2) environmentally adapted and 3) available (Echols and Cuany 1974). An assessment of species occurrences on disturbed alpine sites is an initial step in the selection of species for alpine revegetation (Chambers et al. 1984). Successful revegetation of an alpine disturbance begins with recognition of the unique environmental parameters of the zone and the physiological characteristics of the adapted native plant species. Complete autecological life history studies are necessary to determine tolerance limits for various types of potential alpine plants. Further studies are required to define the climatic amplitudes of particular alpine areas. Synecological studies will also be needed to examine the interactions and interrelations of species when planted in mixtures. Brown and Johnston (1976) and Brown et al. (1976) have shown that most commercially available species are poorly adapted to revegetating disturbed alpine sites. Many of the species mentioned in this text as having potential for revegetation of alpine areas are not in commercial seed channels and have not yet had sufficient testing or guideline development (Brown and Wiesner 1984). This may be partially because these areas have had relatively little information published regarding their rehabilitation as compared to the abundance of research and experience in plant zones at lower elevations. This is understandable because the alpine zone has: 1) a low incidence of permanent human habitation and 2) snow cover, short frost-free

periods, thin soils, steep slopes, strong winds, and other climatic factors imposing significant restrictions on what might be described as "normal agronomic activity" (Eaman 1974).

Seed of varieties in commercial channels are produced in fields under close supervision by the seed dealers. Conditions of production, genetic characteristics, and quality are specified and subsequently certified. In contrast, seeds of alpine species not amenable to cultivation are only available from collections of native populations.

Seed production from wildland populations can be unpredictable from year to year. Meager precipitation, frost, insect damage, disease, and grazing can lower seed quality or even prevent seed production. However, many plant species can be successfully grown and encouraged to produce abundant viable seed crops under field conditions. The reclamation specialist should encourage the production of seed of species adapted to alpine areas under normal field conditions. The alternatives currently available include the direct utilization of seeds harvested from native stands or the utilization of the limited commercially available introduced and native species. The appendix lists the species mentioned in the text as having potential for revegetation of alpine areas in Montana. It also provides comments as to the commercial availability of particular species.

The fact that the alpine zone constitutes a relatively small proportion of the total land area in the state is in no way proportional to its importance to the State or to the impacts that

disturbance to these sites cause. The slowness of plant establishment, limited seed availability of native species, limited soil resources and general difficulty of rehabilitation require that alpine disturbances be kept to an absolute minimum, if we are to ensure the integrity of this zone in the future.

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APPENDIX

APPENDIX

SOME PLANT SPECIES POTENTIALLY USEFUL FOR REVEGETATION OF ALPINE AREAS IN MONTANA WITH NOTES ON ADAPTATIONS AND AVAILABILITY[1]

Scientific Name	Common Name	Availability[2] Recommended Cultivar	Adaptation
INTRODUCED GRASSES			
Agrostis alba L. = A. stolonifera L.	redtop		Acid soils, wet sites
Alopecurus arundinaceus Poir.	creeping foxtail	"Garrison"	Wide range of soils, wet soils
Alopecurus pratensis L.	meadow foxtail		Acid soils, wet sites
Bromus inermis Leysser	smooth bromegrass	"Manchar" "Polar"	Wide Range of soils, well drained sites
Dactylis glomerata L.	orchardgrass	"Latar"	Medium textured soils, well drained sites
Festuca ovina L. var.?	sheep fescue	"Covar"	Medium textured soils, well drained sites
Festuca ovina var. duriuscula (L.) Koch	hard fescue	"Durar" "Arctared"	Medium textured soils, well drained sites

Appendix Continued.

Scientific Name	Common Name	Availability Recommended Cultivar	Adaptation
Festuca rubra L.	red fescue	"Fortress" "Boreal"	Tolerates low fertility soils
Phleum pratense L.	timothy	"Climax"	Wide range of soils, cool, moist sites
Poa compressa L.	Canada bluegrass	"Reubens"	Acid soils, dry sites
INTRODUCED FORBS			
Medicago sativa L.	alfalfa	"Ladak-65"	Wide range of soils, drought, shade and weak acid tolerant
Trifolium hydridum L.	alsike clover		Medium textured soils, cool, moist sites
Trifolium repens L.	white clover	"Ladino-type"	Medium textured soils, cool, moist sites

Appendix Continued.

Scientific Name	Common Name	Availability Recommended Cultivar	Adaptation
NATIVE GRASSES AND GRASS-LIKE SPECIES			
Agropyron latiglume (Scribn.&Sm.) Rydb.=A. trachycaulum var. var. latiglume (Scribn.&Sm.) Beetle	alpine wheatgrass	Not available	Low fertility soils, well drained
Agropyron subsecundum (Link) A.S.Hichc.= A. trachycaulum var. unilateral (Cassidy)Malte	slender wheatgrass	"	"
Agropyron trachycaulum (Link)Malte	slender wheatgrass	"Revenue"	Wide range of soils, well drained sites
Agrostis scabra Willd.	hairgrass	Not Available	Wet meadows
Bromus carinatus Hook. & Arn.	mountain bromegrass	"Bromar"	Moderately moist sites
Carex lenticularis Michx.	sedge	Not available	Wet meadows
Carex nigricans C.A.May.	sedge	"	Wet Meadows
Carex paysonis Clokey	sedge	"	Moist meadows to open rocky slopes
Deschampsia cespitosa (L.)Beauv.	tufted hairgrass	Currently under evaluation, source of seed limited	Meadows, poorly drained soils

Appendix Continued.

Scientific Name	Common Name	Availability Recommended Cultivar	Adaptation
Festuca ovina L. var. brevifolia (R.Br.)Wats.	alpine fescue	Currently under evaluation	Moderately moist rocky open sites
Festuca saximontana Rydb. = F. ovina var. brevifolia (R.Br.)Wats.	alpine fescue	"	"
Koeleria cristata (L.)Pers. nom. Illiget.= K. macrantha (Ledeb.) Schult.	praire junegrass	Source of seed limited	Dry, open slopes
Luzula spicata (L.)DC.in Lam.&DC.	woodrush	Not available	Well drained, rocky sites
Phleum alpinum L.	alpine timothy	Currently under evaluation, source of seed limited	Moist meadows
Poa alpina L.	alpine	Currently under evaluation	Moist meadows
Poa interior Rydb.	inland bluegrass	Currently under evaluation	Moist open slopes
Stipa columbiana Macoun	subalpine needlegrass	Limited seed source	Moist to dry slopes
Trisetum spicatum (L.)K. Richter	spike trisetum	Currently under evaluation	Moderate to moist meadows

Appendix Continued.

Scientific Name	Common Name	Availability Recommended Cultivar	Adaptation
NATIVE FORBS			
Achillea millefolium L.	western yarrow	Limited seed source	Moist meadows to open rocky slopes
Androsace septentrionalis L.	fairy candelabra	Not Available sites	Cool, moist
Antennaria lanta (Hood.)Greene	wooly pussy-toes	"	"
Arenaria faendler Gray	Fendlers' sandwort	"	"
Arenaria obtusiloba (Rydb.)Fern.	Arctic sandwort	"	"
Artemisia scopulorum Gray	sagewort	"	Moist to dry sites
Cirsium sp.	thistle	"	Cool, moist sites
Epilobium alpinum L.	Alpine willow-weed	"	"
Epilobium anqustifolium L.	fireweed	Limited seed source	Moderate to moist sites
Erysimum nivale (Greene)Rydb.	Alpine wallflower	"	"
Geum rossii (R.Br.) Ser. in DC.	avens	Not available	Moderate to moist sites

Appendix Continued.

Scientific Name	Common Name	Availability Recommended Cultivar	Adaptation
Luetkea pectinata (Pursh)Kuntze	partridge foot	Not available	Well drained sites
Lupinus argenteus Pursh	silvery lupine	Currently under evaluation	"
Mertensia viridis (A. Nels.) A. Nels.	green bluebells	Not available	Cool, moist sites
Phacelia sericea (Grah.) Gray	silky phacelia	"	Moderate to dry sites
Polemonium viscosum Nutt.		"	Open, rocky slopes
Polygonum bistortoides Pursh	American bistort	"	Moist meadows
Potentilla diversifolia Lehm.	cinquefoil	Currently under evaluation	Moderate to moist sites
Rumex sp.	dock	Not available	
Sedum lanceolatum Forr.	lanceleaved stonecrop	"	Rocky slopes
Senecio sp.	groundsel	"	
Sibbaldia procumbens L.	sibbaldia	Currently under evaluation	Moderate to moist sites
Silene acaulis L.	moss campion	Not available	Moist, rocky sites

Appendix Continued.

Scientific Name	Common Name	Availability Recommended Cultivar	Adaptation
Thermopsis divaricarpa Nels.	golden banner	"	Moderate to moist sites
Trifolium dasyphyllum T.&G.	whip-root clover	Not available	Moderate to moist sites
Trifolium nanum Torr.	dwarf clover	"	"
Vicia americana Nuhl. ex Willd.	wild vetch	"	"
NATIVE WOODY SPECIES			
Cassiope mertensiana (Bong.)G.Don	Mertens' mountain heather	"	Open, rocky slopes
Juniperus communis L.	common juniper	"	"
Phyllodoce empetriformis (Sw.)G.Don	pink mountain heather	"	"
Salix nivalis Hook. = S. reticulata L.	snow willow	"	Poorly drained meadows
Tsuga mertensians (Bong.)Carr.	mountain hemlock	"	Open, rocky slopes

[1] The species mentioned in the text are grouped according to origin and life form and arranged alphabetically by scientific name follows by common and/or cultivar names. Scientific nomenclature follows Cronquist et al. (1972) for graminoids and Dorn (1984) for all others.

[2] All introduced grasses and forbs are commercially available.