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Reclamation of Drastically Disturbed Lands

This book is a complete revision of the first edition with the same title. With a few exceptions, different authors than those of the first edition have written the chapters in this edition. These revisions follow significant changes in the coal mining reclamation requirements as a result of passage and implementation of the Surface Mining Control and Reclamation Act of 1977 (SMCRA, Public Law 95-87). Passage of this law essentially made many chapters of the first edition out of date by the time the book was published in 1978. The first edition (F.W. Schaller and P. Sutton, editors) was largely the result of proceedings from the Wooster, Ohio, symposium.

This edition is a cooperative effort of the American Society for Surface Mining and Reclamation (ASSMR) and the American Society of Agronomy as a part of mutual liaison activities between these two societies. Chapters and senior authors were suggested to the editorial committee by action of an ad hoc committee of ASSMR.

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21 Reclamation of Alpine and Subalpine Lands

T. M. MACYK

Alberta Research Council
Edmonton, Alberta, Canada

I. INTRODUCTION

Industrial development and recreational use are rapidly expanding in the subalpine and alpine regions of North America. These regions are vitally important as metropolitan, industrial, and agricultural watersheds, providing nearly year-round snow accumulation and water storage areas (Brown et al., 1978). They also are essential wildlife habitat areas.

Exploitation of the vast amounts of minerals and fossil fuels that occur in these areas will continue and likely expand in the coming decades. Pressures for increased recreational opportunities and facilities combined with the natural beauty and recreational experiences offered by these regions also will result in expanded land use. In light of this expanding pressure for development, the major challenge is not to withdraw these areas from reasonable use, but to develop and refine the techniques to return these ecosystems to a natural self-sustaining state (Brown et al., 1978). Clearly, the development of reclamation technology should keep pace with the advances in technology associated with human activities including recreation, exploration, mining, and other endeavors.

Various jurisdictions have different regulations or policies that affect development of these lands. For example, the National Parks in Canada have adopted a zoning system by which areas of a national park are classified according to their need for protection and their capability to accommodate visitors (Parks Can., 1980). The different provinces and states have various policies regarding development, and in some jurisdictions, access to these areas may be limited to designated times of the year.

Reclamation of disturbed areas in the alpine and subalpine represents a major challenge due to the severe climate and relatively limited soil resource compared to other ecoregions. However, based on the research reported in the literature, it is clear that there is progress in enhancing the knowledge base and the techniques for effective reclamation in these regions.

Reclamation of Drastically Disturbed Lands, Agronomy Monograph no. 41.

II. SETTING

The alpine region includes areas above tree line in any mountain range or those portions of mountains above the upper limit of tree growth. Tree line is situated where the contiguous forest ends and isolated islands of trees begin (Ogilvie, 1976). Isolated patches of krumholz and dwarfed trees characteristic of the subalpine can be considered part of alpine ecosystems (Brown et al., 1978). In the USA, tree line occurs at about 3500 m above sea level (ASL) in the Southwest, 2000 m in Montana, and 1500 m in New England (Hardy BBT Ltd., 1990). In Alberta tree line occurs at about 2135 m ASL in the south and 1980 m in the northern end of the province. Tree line in British Columbia is about 2290 m ASL in the Southeast, 1680 m ASL in the Southwest and 900 m in the northern portion of the province. The subalpine region includes the area located between the alpine treeless zone and the montane forest or boreal upland.

III. TYPES OF DISTURBANCE AND IMPACTS

A. Recreation

Brown et al. (1978) stated that recreation may be among the fastest growing causes of disturbance to alpine areas. Cole et al. (1987) reported that the most common problems resulting from recreational use of wilderness in order of frequency are trail deterioration, campsite deterioration, litter, crowding, pack-stock impact, human waste disposal, impacts on wildlife, user conflicts, and water pollution. Off-road vehicles, concentrated use by pack animals on trails, and campsites are a major cause of disturbance in both the alpine and subalpine. Hardy BBT Limited (1990) stated that the development and use of ski facilities and hiking trails are the major source of disturbance in the alpine. Increased access to alpine areas has resulted from the construction of gondola lifts and use of ski resorts during the summer. Other activities include the use of all-terrain vehicles, commercial trail riding operations, back-country camping, and hunting.

Stream sedimentation, erosion, slumping, and vegetation removal are the major impacts of off-road vehicle use. The impact of snowmobile use during limited snowfall winters was evaluated at Niwot Ridge, Colorado, by Greller et al. (1974). The skis and rubber tracks caused soil scraping, removal of lichens, and damage to taller plants. Start-up and rapid acceleration of the machines resulted in entire plant removal.

The impact or disturbances caused by hiking and equestrian use are associated with construction of trails and off-trail use. Trail construction can result in erosion, sedimentation, and the alteration of normal flow patterns of snowmelt and natural drainage channels. Cole (1993) examined the response of 16 different vegetation types to experimental trampling that simulated the effects of hiking. The work was conducted in the mountainous regions of Washington, Colorado, New Hampshire, and North Carolina and changes in vegetation cover, vegetation height, species richness and species composition were evaluated. He found that a larger proportion of the vegetation types in the mountainous western USA appeared to be more resistant to trampling than vegetation types in the eastern states. Cole (1993) also reported that the alpine vegetation types included in this study were more resistant to trampling than many vegetation types found at lower elevations.

B. Mining

Surface disturbances associated with mining include the mining operations as well as the building of roads, railroads and other ancillary facilities. Brown et al. (1978) reported that more than 34,000 ha of alpine tundra have been disturbed in the western USA and that a large proportion of this area is comprised of abandoned operations. Mining of Cr and Pt has occurred in the Beartooth Mountains of Montana while Au and Ag also have been mined in the alpine. Mining activities in the alpine in Alberta and British Columbia are of limited extent, however reclamation research activities have been ongoing for the past two decades (Macyk et al., 1995).

Mining in the subalpine is considerably more common than in the alpine (Fig. 21-1). Historically, surface mining has been considered to be in conflict with virtually every other use to which the land might be put: including tourism, recreation, fish and wildlife, watershed protection, and the preservation of natural areas. Poor management practices have resulted in increased sediment loads and degraded soil quality. Johnston et al. (1975) reported that mining operations in certain geologic formations could result in the movement of high concentrations of acid and heavy metals into surface and subsurface waters. It also should be

Fig. 21-1. Surface mining for coal in the subalpine.

noted that many of the problems identified were associated with abandoned operations or those operations initiated prior to the more stringent regulations and improved mining practices that have evolved over the past two decades. Underground mining operations, which have some of their own problems, do not create the amount of disturbance associated with surface operations.

C. Grazing

Brown et al. (1978) reported that many alpine ranges in the USA have been used for summer grazing by livestock, mainly sheep, since the mid-1880s. Grazing by domestic livestock is not encouraged above 1500 m in the eastern slopes of Alberta and is not a significant disturbance in alpine areas.

D. Roads

Disturbance caused by road construction is associated with industrial activity including oil and gas exploration and production, mining, access to forestry lookout towers and tourist facilities, and maintenance roads at ski resorts. The major concerns are related to erosion that commonly occurs on the steeply sloping terrain. Impacts include increased sediment production, changes in flow patterns, water quality deterioration, and the potential for reduced productivity of aquatic systems. Improved engineering design standards for roads and more stringent land conservation and reclamation guidelines have assisted in minimizing problems.

E. Other Disturbances

Although exploration activities for coal, oil and gas are more common in the subalpine than the alpine (Fig. 21-2), pipelines, power lines, hydroelectric dams and other facilities are not a major source of disturbance in either zone. Pipeline construction generally involves a narrow band of surface disturbance and movement of drilling equipment is the major source of impact associated with power line construction. Fire, landslides, and avalanches are the major natural large-scale causes of disturbances.

IV. ENVIRONMENTAL FACTORS AFFECTING RECLAMATION

Thilenius and Smith (1985) concluded that exposure to prevailing wind, elevation, soil particle size distribution, available water content, and snow accumulation were statistically significant environmental factors determining community type distribution of alpine vegetation on Carter Mountain in the Absaroka Range of northwestern Wyoming. These same parameters also are critical to revegetation and reclamation success in the alpine and subalpine regions.

A. Soils

Climate is the dominant soil-forming factor in the alpine and subalpine regions. High contents of weakly decomposed organic matter in the surface hori-

Fig. 21-2. Exploration activities in the subalpine.

zons, weak granular structure, and low clay content are typical of alpine soils in North America (Knapik et al., 1973; Retzer, 1974). Alpine soils are generally much less uniform than soils occurring at lower elevations (Hardy BBT Ltd., 1990) and tend to form a complex fine scale mosaic (Holland & Coen, 1982). Well-drained stable slopes are often characterized by Alpine Dystric Brunisols (Cryochrepts and Dystrochrepts) that have surface horizons containing high organic matter levels. Wind-swept ridges that are snow-free in winter typically have Orthic Regosols (Entisols) with thin sola and surface A horizons formed by the physical mixing of mineral and organic material. Soil creep and frost action results in buried and truncated soil pedons. Orthic and Cumulic Regosols (Entisols) are common on late snowbed sites where soil creep has resulted in mixing of the soil. Gleysolic (Aquepts) soils are common in areas of ponded runoff and groundwater discharge. Soil profile depths in the alpine are highly variable. An example of a relatively shallow soil profile is illustrated in Fig. 21-3.

Soils of the subalpine occur mainly on steep slopes with thin till and colluvial veneers overlying bedrock (Macyk & Widtman, 1985). Soil profile thickness ranges from 5 to 60 cm with an average effective rooting depth of 25 to 45 cm. Rock outcrops are common and solum thickness changes abruptly over short distances (Fig. 21- 4). The dominant soils include Brunisols, (Dystrochrepts and Eutrochrepts), Luvisols (Boralfs), Regosols (Entisols), and poorly drained Humisols (Aquepts and Humaquepts). Coarse fragment content is variable and dominant textures in the sola range from fine sandy loam to silt loam. The soils occurring in the glaciofluvial and alluvial deposits at lower slope positions and

Fig. 21-3. Shallow soils typical of the alpine region.

Fig. 21-4. Shallow soils typical of the subalpine region.

valley bottoms generally represent the best soil materials for revegetation in the region. The poorly drained soils often represent an excellent source of organic matter for improving the overall quality of reconstructed soils, however drainage prior to salvage may be required to expedite the soil removal process.

B. Climate

Climate is the most limiting factor to reclamation success in the alpine and subalpine regions. Temperature regime, including length of growing season, precipitation, and wind, are some of the most critical parameters and are summarized below.

1. Temperature

Billings (1974) described alpine ecosystems as having low heat budgets that result in short, cool growing seasons ranging from 45 to 90 d in length. He reported a mean growing season air temperature of about 8°C in midlatitude alpine areas. Hardy BBT Limited (1990) reported an estimated mean summer temperature of 6.5°C for the alpine ecoregion in Alberta. Temperatures vary widely both areally and annually. For example, Macyk and Pojasok (1995) reported mean growing season temperatures of 5.3° and 8.3°C for 1993 and 1994, respectively, at an alpine research site (2100 m ASL) approximately 150 km north of Jasper in the Rocky Mountains in Alberta. They reported a frost-free period of 64 d in 1994 compared to only 28 d in 1993.

Soil temperatures are extremely variable depending upon aspect and surface soil characteristics. Macyk and Pojasok (1995) reported maximum soil temperatures of 45°C on the surface of cover soil with 60% coarse fragment content compared to maxima of 35°C in soils with a coarse fragment content of 15% during July and August. The higher soil temperatures at the site with higher coarse fragment content were not high enough or of sufficient duration to be limiting to plant growth. Conversely, higher soil temperatures combined with adequate moisture levels are an advantage in maximizing growth potential in the short growing season of this area.

Air temperatures in the subalpine also are variable but somewhat higher than in the alpine. In a monitoring program underway since 1983 at three locations in a subalpine mine site (1750 m ASL), growing season temperatures averaged from 9° to 12°C. Frost-free period ranged from 45 to 110 d with a mean of 85 d over the 12 yr of measurement (Macyk et al., 1995). Soil temperatures measured at the 2-cm depth at different slope aspects reached average values of 46°C for several consecutive hours on consecutive days on crown and south-facing positions. Temperatures in excess of 50°C were reported for the surface of soils containing significant amounts of black coal waste materials. Surface temperatures of 45° to 50°C can cause stem girdle of tree seedlings, particularly if soil moisture levels are low (Day, 1963).

2. Precipitation

Precipitation also is extremely variable throughout the alpine and subalpine regions of North America. Billings and Mooney (1968) reported annual precipitation of about 634 mm at Niwot Ridge in Colorado (3476 m ASL) and Brown and Johnston (1976) reported mean annual precipitation of 1200 mm on the Beartooth Plateau in Montana where only about 10% occurs during the growing season. Hardy BBT Limited (1990) reported precipitation ranging from 570 to 970 mm in the alpine region of Alberta with about 48% occurring during the growing season. Macyk and Pojasok (1995) reported rainfall of 353 and 327 mm during the growing seasons of 1993 and 1994, respectively, at their alpine research site. At their subalpine research site the mean annual growing season precipitation over 22 yr of measurement was 260 mm with values ranging from 130 to 475 mm (Macyk et al., 1995). Differences in growing season precipitation varied as much as 50% between two stations only 2 km apart.

The precipitation total for a growing season is important, however distribution of the rainfall throughout the season and intensity of rainfall events are critical for plant establishment and growth. For example, receiving 50% of a monthly rainfall total in 1 d suggests that significant runoff will occur. This is certainly true of events with 1 mm of rain occurring per minute over a 5- to 10-min period.

During winter in the alpine and subalpine, snow distribution is widely variable. Southwest-, west-, and northwest-facing slopes may be completely free of snow, whereas east- and north-facing aspects or sheltered areas may have snow several meters deep that may remain until well into the summer or potentially year-round (Strong & Leggat, 1981).

3. Wind

Strong and persistent winds are common in the alpine and subalpine and vary widely in terms of velocity and impact in the different topographic settings. Wind influences snow distribution by maintaining snow-free areas on exposed slopes and ridges, and blowing snow onto leeward slopes. Vegetation on open slopes is exposed to severe wind chill, desiccation and abrasive damage. Plants on lee slopes may have shortened growing seasons due to accumulation of snow. Strong winds erode soil particles from disturbed sites, reducing water and nutrient holding capacities (Brown et al., 1978). Furthermore, winds erode and redistribute seed in areas where the seed has not been well incorporated and can have a severe impact on broadcast seeding and hydroseeding operations.

Macyk and Pojasok (1995) reported average monthly wind speeds of 30 to 40 km h^{-1} during the October to March period and 20 to 30 km h-' during the remainder of the year at their alpine research site (2100 m ASL). Maximum wind speeds recorded were in the range of 125 to 150 km h^{-1}. Similar measurements at their subalpine monitoring sites indicated that during some months of the year maximum velocities in excess of 70 km h^{-1}
10 d (4 wk)/mo^{-1} . Strong winds, especially during the winter, combined with cold temperatures and minimal snow cover have been devastating to vegetation establishment, particularly newly planted tree and shrub seedlings (Macyk & Widtman, 1987).

Knowledge of prevailing wind direction has been useful in reclamation planning, including soil replacement strategies and selection of vegetation species. Prevailing winds can be used to transport seed from "island" vegetation areas to a larger portion of a disturbed area.

V. SOIL HANDLING STRATEGIES

Soil salvage and replacement is an integral part of the materials handling program associated with surface mining and other surface disturbing activities. A replaced cover soil or soil topdressing is usually a better medium for plant growth than spoil that in these regions is primarily fragmented rock with variable particle size. The cover soil is comprised of the salvaged organomineral surface material and the underlying B horizon mineral material overlying bedrock.

A. Predisturbance Soil Assessments

Prior to most land-impacting activities, the proponent must provide the appropriate regulatory agencies with a plan detailing what the baseline or undisturbed condition is, the nature of the activity or disturbance, and how the land will be reclaimed. Completion of a soil survey with relevant interpretations helps provide an understanding of the soil and plant relationships in an area prior to preparing a development plan to ensure adequate evaluation of the potential for reclamation. Assessment of the suitability or quality of the different soils will allow for planning selective salvage and replacement of materials. Approximate volumes of soil material available for salvage and subsequent replacement can be determined.

B. Soil Salvage and Replacement

Because the surface or organomineral horizons are minimal or nonexistent, and the sola are quite variable in thickness, segregation or selective handling of soil materials is generally not considered in the alpine and subalpine (Fig. 21-5). The use of large equipment, combined with the variability in depth of soil overlying bedrock, inherently results in the incorporation of varying quantities of coarse fragments into the soil removed. Slope angle also restricts the total area from which the soils can be effectively and safely salvaged.

The replaced soil provides three basic requirements of plants including a supply of moisture, nutrients, and a medium for root development or mechanical support. In most instances, the salvaged and replaced soils are relatively low in available nutrients, but they have better moisture holding capacity, and provide a better medium for root development, at least in the early stages of plant development than the spoil material.

Brown et al. (1976) working on the Beartooth Plateau in southern Montana reported that severe drought in the upper 15 cm of soil was a greater cause of seedling mortality than low fertility or unfavorable soil chemical properties. Brown (1984) suggested that the texture and associated moisture holding capability of topsoil is its most useful attribute. Others, including Berg and Barrau (1978), reported that replacing topsoil could reduce the need for maintenance fertilizer addition to coarse spoil material in the subalpine. Another benefit of soil salvage is the incorporation of seed and vegetative material during soil salvage operations and the resultant germination of seed and/or sprouting of vegetative material following soil replacement. Direct placement is generally not an option, so the soil material is stockpiled and used as required (Fig. 21-6).

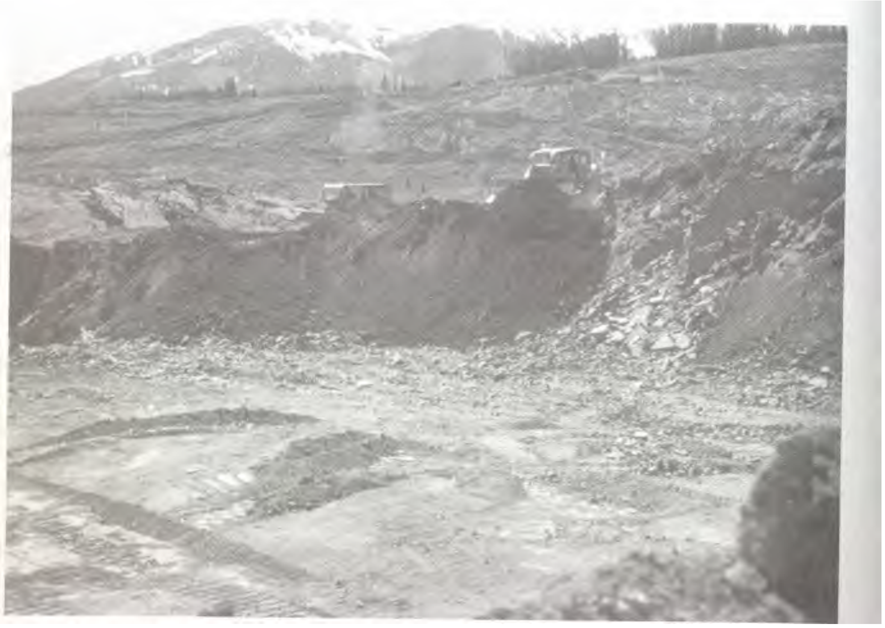

Fig. 21-5. Selective handling of soil materials is not practical in the alpine and subalpine. Soils are salvaged in one lift.

Fig. 21-6. Soil material previously salvaged and stockpiled is replaced following spoil grading.

The key to maximizing the usefulness of replaced soils is to emphasize "soil quality" over "soil quantity" during the salvage operations. Salvaging unsuitable materials, which might include very fine-textured soil or, soils high in free carbonates is not beneficial. Mixing unsuitable soil materials with more suitable material results in reduced soil quality overall. In contrast to agricultural topsoils, the presence of coarse fragments is beneficial for replaced cover soils in the alpine and subalpine. Coarse fragments provide improved microclimate conditions by providing protection from winds and are beneficial in reducing erosion, especially on steep slopes. Wood debris including logs and branches as well as boulders also can be strategically placed to provide protection and enhance microclimate.

The thickness of the replaced cover soil is a function of the amount available prior to salvage and the efficiency of the salvage and replacement operations (Fig. 21-7). Therefore, there is no basis to arbitrarily suggest that a specific soil thickness should be replaced at all sites. Factors such as soil quality and the characteristics of the spoil material also must be considered. In some instances, the graded spoil may have better growth support characteristics than the soil material available. In general however, a 5- to 10-cm layer of replaced soil is considered to be the minimum desirable. A layer less than 10 cm may be impractical to apply, especially on fragmented rock spoil and on steep slopes. It may be practical to replace thin layers (5 cm) on level surfaces where the spoil materials contain a significant proportion of fines at the surface. Layers less than 15 cm thick in the subalpine region are often not suitable for planting bare root or container seedling stock due to the difficulty in achieving proper planting and subsequent survival.

Replacement of cover soil layers thicker than 15 cm would involve the use of predominantly mineral rather than organic material and can result in problems that are related primarily to the placement technique. For example, replacement of a soil layer 30 to 45 cm thick on a sloped surface would require a number of heavy equipment passes over a given area with soil being moved downward from the crown or top of the slope. The heavy equipment traffic results in a crusted surface and compacted soil, especially if the moisture content is relatively high. Similarly, thicker layers of soil may slump or slide downslope, particularly if the underlying spoil was graded to a smooth surface prior to soil placement.

Cover soil should be replaced in a manner that will result in optimum revegetation of an entire area including management of a limited supply of soil by placing the soil in locations where it will be most useful. This suggests that greater thicknesses may be replaced in some locations and that others may receive no soil at all. For example, placement of soil in windswept positions will result in more soil loss than occurs in more sheltered locations. This is especially critical in alpine areas.

Following soil replacement, the soil surface should be loosened prior to seeding or planting unless the seeding operation is to occur immediately after soil placement and leveling. One rain event followed by drying conditions in these areas is usually enough to result in a crusted surface on replaced soil that is low in organic matter. Conventional agricultural equipment is seldom effective in "cultivating" these soils due to the nature of the soil (coarse fragments) and the

Fig. 21-7. Reconstructed soil with 20 cm of cover soil overlying rock spoil.

slopes involved. Most operators custom build equipment that will withstand the soil conditions and the large machines that pull it over the area. Macyk (1975) reported the use of a custom-made "drag" used at the operations of McIntyre Mines Ltd. Others have used custom-made harrows that may involve welding metal teeth onto a sturdy frame (Walker, 1981) or attaching lengths of heavy chain to a pipe drawbar. In most cases, the intent is to loosen the soil surface prior to seeding, and following seeding, to incorporate the applied seed and fertilizer to minimize the amount exposed at the surface.

The effects of microenvironment are very important in the open and windy subalpine and alpine regions. Rough grading creates microsites for protection and moisture collection that are favorable for plant establishment. Protection for emerging plants is considerably more critical in the alpine than the subalpine.

VI. REVEGETATION STRATEGIES

Successful revegetation is dependent upon the preparation of a suitable growth medium and the selection of appropriate species. Assessing the plant cover prior to disturbance and surveying adjacent undisturbed areas or early successional sites can identify plant species suitable for a disturbed area. Land use drives the species selection for a disturbed area. In the alpine, land use is primarily for recreation and wildlife habitat. In the subalpine, the uses are similar with some potential for noncommercial and commercial forest production in selected locations. In national parks, revegetation involves re-establishment of the species that existed prior to disturbance.

Revegetation programs over past decades in the subalpine have used introduced species. Reference was often made to the fact that native species should be used because animals prefer them, that less maintenance is required after establishment, and that natives are more aesthetically pleasing. Realistically, however it is only in recent years that seeds for native species became available on a commercial scale, or in amounts that would allow for operational scale seeding efforts. Brown and Chambers (1989) stated that the seeds of most native alpine plant species suited for revegetation are not commercially available and must be hand-collected. Macyk (1985) also reported that seeds for selected native species were collected in the undisturbed areas adjacent to a disturbed mine area and subsequently cleaned and planted. Great strides have been made in producing materials suitable for commercial applications in the alpine and subalpine (Acharya, 1989; Darroch & Hermesh, 1991).

Introduced species are currently more commonly used in the subalpine than in the alpine, primarily due to adaptability to site conditions. The role of introduced species is to provide initial cover to minimize the potential for erosion and to assist in the restoration of the functions of the reconstructed or replaced soil material. Introduced species become established relatively uniformly within 1 to 2 yr after seeding, thereby providing protection against soil erosion and contributing to improved soil porosity, decreased compaction, and enhanced or improved moisture infiltration. Depending upon the species and climatic conditions, introduced species will mature, produce viable seed, and promote the existence of the cover. Selected introduced species play a major role in the natural invasion by natives and in the subalpine, the establishment of trees and shrubs. The initial cover comprised of introduced species can provide site conditions suitable for native grasses and legumes to thrive and protection for trees and shrubs during their critical initial establishment phase. However, Chambers et al. (1994) in their work at the Wooley Valley phosphate mine in Idaho, reported that natural successional processes were not resulting in reclaimed areas that resemble native reference areas.

A. Species Selection

Brown and Chambers (1989) stated that one of the most important factors in ensuring successful reclamation is the selection of plant species that are suited to the limiting environmental factors characteristic of a disturbance. Adapted species are those capable of long-term survival and reproduction.

1. Grasses and Legumes

The literature contains a large amount of research on the selection of plant species suitable for use in reclamation of disturbed areas in the alpine and subalpine. Research projects in the 1960s and 1970s were designed to evaluate the suitability of a large number of species especially where introduced species were being used. For example, Hendzel (1976) seeded 40 grasses, Macyk (1972) seeded 30 grasses and legumes, Takyi and Islam (1985) evaluated 21 agronomic species, Brown (1974) tested over 20 species of grasses, Errington (1979) tested 23 species, and Gates (1962) evaluated 12 species. These researchers and numerous others achieved varying levels of success with the species they evaluated. It is apparent that species adapted for successful revegetation in Colorado may not be as useful in northern Alberta or northern British Columbia and vice versa.

Grass species are the most commonly used plants in revegetation. During the 1960s and 1970s the goal of revegetation trials was to identify the most suitable species for selected areas and to maximize the growth or cover achieved to demonstrate that revegetation was possible. These areas also were fertilized to maintain dense cover, resulting in minimal change in diversity for several years. However, with time, the thinking and approach to revegetation practice changed with the recognition that maintenance of a dense and relatively closed plant community was not necessary and would not meet long-term objectives. Seed mixture composition, vegetation management practices, and fertilization strategies became the focus of revegetation activities. In long-term work conducted by Macyk and Pojasok (1995), it became evident that in areas seeded with mixes containing selected grasses and legumes, withdrawal of fertilizers reduced the grass component of the stand and promoted invasion by natives (Figs. 21-8, 21-9, 21-10, 21-11). The extent of invasion varies with site characteristics, introduced species used, and management practices. For example, Chambers et al. (1994) reported that reclamation methods including fertilization, high seeding densities of forage grasses and legumes, and mulch crimped into the soil promoted the production of highly competitive forage species that resulted in limited establishment of native species. This situation was aggravated by alfalfa *(Medicago sativa L.),* which increased as N levels decreased with time after fertilization.

Low-growing perennial herbaceous or shrub species with large underground root systems are typical of the alpine region. Brown and Chambers (1989) indicated that the total flora of alpine ecosystems is smaller than that of lower *elevation* zones, and the pool of adapted species for revegetation is limited. Although

Fig. 21-8. Reconstructed area in the subalpine following cover soil replacement.

Fig. 21-9. Grass species dominate initial cover established in area depicted in Fig. 21-8.

Fig. 21-11. Trees and shrubs comprise a significant portion of the cover 15 yr after initial seeding. Native species invade with the decline in the initial grass cover.

introduced plant species commonly used for revegetation at lower elevations are often unadapted for use in the alpine, a number of agronomic species have been developed that can be successfully established in the alpine. The persistence of these species and the production of viable seed vary depending upon the species used and site factors.

The lack of availability of native seed for revegetation has been a problem in the past, however the situation has improved significantly in recent years. Selection programs such as those at the Environmental Plant Centre (EPC) at Meeker Colorado and the Vegetation Branch of the Alberta Environmental Center (AEC) are contributing to the species that are available. For example, the AEC (Darroch & Hermesh, 1991) undertook a program to select, test, develop, and register lines of native grasses including alpine bluegrass *(Poa alpina L.),* slender wheatgrass *[Agropyron trachycaulum* (Link) Malte var. *unilaterale* (Cassidy) Malte], broadglumed wheatgrass (A. *violaceum),* spike trisetum *[Trisetum spicatum (L.)* Richt] and sheep fescue *(Festuca saximontana* Rydb.). Brown and Chambers (1989) reported a number of native alpine grass and forb species that were established on disturbed sites from seeds. These included slender wheatgrass *(Agropyron trachycaulum),* Scribner wheatgrass *(Agropyron scribneri* Vasey) Payson sedge *(Carex paysonis* Steud), tufted hairgrass [*Deschampsia caespitosa (L.)* Beauv.] alpine timothy *(Phleum alpinum L.),* alpine bluegrass *(Poa alpina),* spike trisetum, western yarrow *(Achillea millifolium L.),* alpine sagebrush *(Artemisia scopulorum),* alpine avens (*Geum rossii* Pursh.), varileaf cinquefoil *(Potentilla diversifolia* Lehm.), and prostrate sibbaldia *(Sibbaldia procumbens L.).* Additional testings of suitable species are available in Johnson and Billings (1962), Greller (1974), Bell and Bliss (1973), Polster (1975), Willard and Marr (1971), Wheeler and Sawyer (1982), Carlson (1986), Guillaume et al. (1986), Walker et al. (1977), Weijer and Weijer (1983), Hassell et al. (1983), Errington (1979), Ziemkiewicz (1977), Macyk (1985), Macyk and Pojasok (1995), and Berg and Barrau (1978).

Hand collection is often done to augment the limited supply of commercially available native seed. Seed collection from local populations adjacent to the disturbed area improves the chances for successful establishment. Urbanska (1985) stated that seed production by alpine plants is dependent upon environmental conditions and dramatic variations can occur from year to year. Chambers (1989) reported significant differences among years and species in seed fill for grasses, and viability for grasses and forbs for seed collected on the Beartooth Plateau in Montana. These differences were attributed to variability in climatic factors including dates of snowmelt, timing and amount of precipitation, and ambient air and soil temperatures. Grasses were found to have lower and more variable seed viability than forbs. Uneven ripening, poor yield, and difficulty in harvesting due to decumbent growth habit or small awns can make acquisition of seed by hand-collection expensive.

2. **Trees and Shrubs**

The discussion of tree and shrub establishment is related primarily to the subalpine region where the dominant land use is wildlife habitat, with lesser emphasis on noncommercial and commercial forest. Successful reclamation of disturbed areas for wildlife involves provision of the basic requirements for food, water, cover, and range and to re-establish diverse and self-sustaining plant communities that will benefit a wide variety of wildlife. Target species for the subalpine often include bighorn sheep *(Ovis canadensis* Shaw), black bear *(Ursus americanus* Pallas), grizzly bear *(Ursus arctos* Linnaeus), elk *(Cervus canadensis* Erxleben), mule deer *(Odocoileus hemionus* Rafinesque), mountain goat *(Oreamnos americanus* de Blainville), Rocky Mountain caribou *(Rangifer arcticus* Gmelin), Rocky Mountain cougar *(Felis concolor* Linnaeus), rabbit *(Lepus americanus* Erxleben), mouse *(Peromyscus spp.* Glogus), hawk *(Accipiter buteo),* golden eagle *(Aquila chrysaetos* Linnaeus), and grouse *(Bonasa umbellus* Linnaeus). Habitat creation must take into account the needs of the wildlife for cover, thermal cover, calving and fawning areas, and water.

The conventional techniques for tree establishment include production and planting of bare root and container stock for conifers. Different types and sizes of containers are available for the particular needs of individual species and the reconstructed sites. Macyk and Widtman (1987) reported that survival rate of engelmann spruce *(Picea engelmannii* Parry) and lodgepole pine *(Pinus contorta* var. *latifolia* Engelm.) increased with increasing size of container where planting was done in rock spoil with a 15- to 20-cm layer of replaced cover soil. Balsam poplar *(Populus balsamifera* L.) stem cuttings and quaking aspen *(Populus tremuloides* Michx.) root cuttings are usually prerooted and then planted in the field.

Shrubs provide floristic and structural diversity in areas of grass and legume cover and are important in slope stabilization (Schiechtl, 1980). From a wildlife standpoint, shrubs are important in ungulate nutrition, providing a source of essential vitamins in winter months and providing most of the available forage in years with heavy snowfall (Leege & Hickey, 1977). Re-establishment of shrubs is particularly important in areas that have the potential to be used as winter range.

Shrubs perform numerous other important functions. Willow *(Salix spp.)* and alder *(Alnus spp.)* are excellent "nurse" species for conifers and other plants (Fig. 21-12). Their low spreading nature makes them an excellent trap for leaf litter, which is quickly processed by soil organisms. Tree seedlings growing adjacent to shrubs show more vigor and have better growth because of the protection afforded them, as well as the nutrients provided by the N- fixing shrubs such as alder (Macyk & Widtman, 1987).

Alder *[Alnus crispa (Ait.),* A. *sinuata* (Regel), A. *tenuifolia* Nutt.] is a dense thicket- forming, deciduous N-fixer that grows on a wide range of well-drained to moist sites. It can be propagated by rooted cuttings and/or planting of seed. Silverberry *(Elaeagnus commutata* Bernh.) is a deciduous N-fixer that thrives on well-drained soils and also can be propagated by seeding or planting rooted cuttings. Prickly rose *(Rosa acicularis* Lindl.) is a bushy, deciduous suckering shrub. It has some value as a browse species and the fruit is eaten by grouse and other birds. It can be propagated from seed or by transplanting of vegetation islands removed from undisturbed areas. Willow is a wide ranging, fast growing, and adaptable shrub that will grow on a variety of soil and spoil materials and in areas with moisture regimes varying from very wet to very dry. Willow is an important

Fig. 21-12. Tree seedlings in their initial establishment stage benefit from the protection provided by the grass cover and shrubs.

browse species on winter range and can be propagated using prerooted cuttings or by directly planting cuttings.

Alpine shrubs including white mountain avens *(Dryas octopetala* L.) and alpine bearberry *[Arctostaphylos rubra* (Rehder and Wils.) Fern] can be readily propagated by seed (Walker & Harrison, 1986). Moss Campion *(Silene acaulis L.),* yellow mountain-heather *[Phyllodoce glanduliflora* (Hook.) Coville], purple mountain-heather *[P. empetriformis* (Smith) D. Don], woolly everlasting *[Antennaria lanata* (Hook.) Greene], and purple saxifrage *(Saxifrage oppositifolia L.),* can be propagated from softwood cuttings (Walker & Harrison, 1986).

In the subalpine, it is beneficial to plant tree and shrub materials in areas with an established grass or grass and legume cover (Macyk & Widtman, 1987). This practice has been questioned because of an anticipated competition for moisture and the increased potential for small mammal damage. However, the protection afforded the seedlings or cuttings by the grass and legume cover, especially in holding snow in the winter, far outweighs the negative aspects of moisture competition during the growing season. Climatic conditions in the subalpine dictate that some form of protection is critical for seedlings and cuttings during the initial establishment phase. During the winter it is not unusual to have the snow cover blown off by strong winds or melted down during periods of warm weather. Subsequent cold spells, especially if accompanied by strong winds, can be particularly detrimental to young seedlings. During the summer, surface and near surface (2-cm depth) soil temperatures have been measured at near 50°C for several consecutive hours on consecutive days in areas without a grass and legume cover (Macyk & Widtman, 1986). Temperatures at the same depths under a vegetative cover were 10°C lower.

Container-grown seedlings are superior to bare root stock in terms of survival and growth rate (Macyk & Widtman, 1986). This can be attributed to the difficulty in planting bare root stock in the cover soils, which contain a significant component of coarse fragments, and the moisture stress that often occurs. Container seedlings have the advantage of the moisture holding capability of the peat or growth medium to retain and supply moisture during periods of moisture stress.

It also is important that planting of trees and shrubs be delayed for at least three or more years after initial seeding of grasses and legumes in an area. This allows the root systems of the established cover to improve the porosity and moisture-holding characteristics of the replaced cover soil. Fertilizer addition should be withheld from the area at this time making the existing cover somewhat less competitive.

Direct seeding is a viable alternative for tree and shrub establishment. Observations in most disturbed areas in the subalpine indicate the establishment of trees and shrubs by natural means. Seed for trees and shrubs is not as readily available commercially as seed for native grasses and legumes. Cone and seed head collection and seed extraction are critical in obtaining viable seed. Fall seeding has been more effective than spring seeding (Macyk & Widtman, 1987). The physical characteristics of the soil surface, especially the degree of crusting and coarse fragment content, are the major influences on germination and subsequent growth.

3. Seeding Techniques

Brown and Chambers (1989) reported that determining seeding methods involves knowledge of the seed germination requirements of different species. Seed size dictates the depth of seeding, with small seeds having difficulty emerging if planted too deeply, and larger seeds needing deeper placement to prevent desiccation during dormancy and seedling development. Other species must be planted at or near the soil surface due to a requirement for light during germination (Brown & Chambers, 1989). Broadcasting, hydroseeding, and hand seeding are the most commonly used techniques for seeding in the alpine and subalpine. Drilling equipment is not commonly used because of the terrain and the coarse fragment content of the soil surface.

Wind is a major limiting factor for broadcast seeding, especially in the alpine. Aerial seeding is very seldom used due to the persistence and velocity of winds. Fertilizer application is not as severely affected by wind as is seed application. Hand broadcasting, although difficult and labor intensive, is very effective. Where slope conditions permit, all-terrain vehicles with attached broadcast equipment are used. Broadcast application allows the seed and fertilizer to settle into cracks and spaces between soil clods or rock fragments. Site preparation prior to seeding, and some form of incorporation following seeding, is critical to seed germination and plant establishment. If seeding is undertaken shortly after cover soil replacement, or prior to crusting caused by rainfall, surface preparation is not required prior to seeding. However, if the surface is crusted, it is difficult for broadcast seed to settle into the microsites necessary for germination and seed loss from wind erosion can become significant. Therefore, wherever terrain conditions permit, some preseeding surface "scarification" should be undertaken to provide conditions appropriate for germination. Similarly, after seeding some form of surface scarification is necessary to incorporate the seed and fertilizer applied. Again, this procedure is necessary to provide close seed-soil contact and to minimize losses due to wind. Brown et al. (1976) recommended that areas seeded by broadcast techniques in the alpine be raked to cover the seed and then firmly packed. In a study to evaluate several seeding methods at the Climax Molybdenum Mine in Colorado, Brown (1974) used a length of chain-link fence as a harrow to mix and cover the seed and fertilizer.

Hydroseeding is generally used on steep slopes and is particularly useful on long slopes where access for equipment is available at both the top and base of the slope. This technique which is commonly used in highway reclamation is described in Booze-Daniels et al. (2000, see Chapter 35).

Hydroseeding can be quite successful where the seedbed has been prepared prior to application or the surface is loose and not crusted. One of the disadvantages of hydroseeding is that in areas that have coarse fragments on the surface, the seed and mulch mixture becomes plastered to the rock surfaces where it dries and results in no germination. For this reason, the amount of seed applied is often higher than the rate that would be applied by conventional broadcast methods. Broadcast seeding followed by hydromulching may result in better vegetation establishment. A variety of commercial mulches are currently available.

Another caution regarding hydroseeding relates to the amount of fertilizer added to the mixture prepared and the residence time of the seed and fertilizer mixture in the tank prior to application. Macyk and Widtman (1993) completed an experiment to determine the relative viability of brome grass (*Bromus inermis* Leyss.) seed treated under hydroseeding and control conditions. The major variables included the length of time that seed was immersed in the fertilizer solution used and drying vs. nondrying of the seed after being removed from the solution prior to germination. Two scenarios were used to simulate conditions that occur in the field, i.e., drying of the hydroseeded material prior to a rainfall event and the converse. The results of the experiment showed that exposure of the seed to the fertilizer solution delayed germination time and resulted in poorer root development and less vigorous plants. A 30-min period of seed exposure to the fertilizer solution was just as damaging as 120 min of exposure. The value obtained from using a fertilizer in solution, especially N, is questionable due to the losses that occur before the plant has developed a root system that is able to utilize the nutrients.

4. Time of Seeding

Seeding of disturbed alpine areas should be done in the fall especially if native species are used. Fall seeding is equivalent to fall seed dispersal with seeds remaining in the soil over the winter and germination and emergence occurring in the following spring. Brown and Chambers (1989) reported that seeding late in the fall mimics natural seed dispersal and enhances seedling establishment. They also reported that fall seeding exposes the seeds to cold dormancy during the winter and permits stratification for species requiring it. Seeding should be done as late in the fall as possible to minimize the opportunity for germination to occur. Timing is difficult for the alpine because of sudden weather changes, especially snowfalls that may delay seeding operations to the following spring. Alternatively, favorable weather following a snowfall may result in snowmelt and the germination of the seed. Therefore, timing of seeding is site-specific and variable from year to year.

Spring seeding in the alpine generally occurs between mid-June and mid-July depending upon location and slope aspect. The risk associated with spring seeding is that dry conditions with relatively high soil temperatures will delay germination, which increases the potential for seed loss due to wind. Furthermore, it is likely that conditions suitable for initiating germination can be followed by prolonged dry and windy conditions that desiccate the germinants, resulting in poor seedling establishment.

Seeding time options are a bit more flexible in the subalpine as conditions are not as severe and introduced species are more commonly used. The options include spring (May to mid-June) and fall seeding with the fall seeding done as late as possible in the season. Generally, seeding prior to the end of May will benefit from late spring snowfalls that commonly occur in the latter part of May or early June. However, timing of seeding in the fall should be such that germination does not occur until the following spring. Introduced legumes are extremely sensitive to frost damage resulting from fall germination. Macyk (1974) reported that alfalfa had better germination and subsequent growth when seeded in the spring than in the fall. For this reason, legumes were not included in seed mixtures recommended for fall seeding.

Seeding in the summer months is not recommended for the subalpine region. The potential for prolonged dry and windy conditions following germination can result in poor plant establishment.

5. Seeding Rates

Seeding rates are commonly based on a recommended weight per unit area. Brown and Chambers (1989) indicated that seeding rates based on the number of viable seeds per unit area ensures that potential competition among species will be uniform over the area and provide optimum potential for seedling survival. Since germination of native alpine species varies according to year of collection and site, this should be considered in determining seed application rates.

Recommended seed application rates range from about 200 to 500 total viable seeds m^{-2}, depending on the site conditions and species used (Brown & Chambers, 1989). Seeding rates used for harsh sites should be near the upper value whereas rates for more favorable sites would likely be near the lower value. Brown and Chambers (1989) reported that from their experience with alpine disturbances, only about 25 to 80% of the viable seed applied germinated and emerged.

In the subalpine, seeding rates for introduced species evolved from rates used in other applications such as rangeland and forage production. Recommended seeding rates established for drill seeding often are increased to compensate for broadcasting on steeply sloping topography with coarse fragments on the soil surface. This approach implies that increasing the seeding rate will ensure the establishment of an adequate vegetation cover.

6. Fertilizer Application

The available nutrient levels of the undisturbed and reconstructed soils in the alpine and subalpine are quite low. Brown and Chambers (1989) reported that N and P are the most limiting nutrients in disturbed areas and that the responses to these nutrients by individual species vary widely. Fertilizer application is considered essential for successful and timely establishment of plant cover on all disturbances ranging from establishment of a lawn in a location with a favorable climate and good soils to revegetation in the alpine and subalpine. The application rate and composition of the fertilizer required varies from site to site due to the general site characteristics as well as nutrient content of the replaced topsoil or cover soil.

Brown et al. (1976) considered fertilizer applications necessary for the successful and rapid establishment of plant cover on alpine disturbances. They recommended that application rates be based on soil testing. The fertilizer should be applied just prior to seeding and mixed to the 6- to 7-cm depth to be available within the rooting zone of germinating seedlings and developing young plants. Unfortunately, replaced soil characteristics in the alpine and subalpine preclude incorporation of seed and fertilizer much beyond the 2- to 3-cm depth in most cases.

The effect of repeated fertilization on species composition, plant cover, plant density, and above- and belowground productivity was investigated by Brown et al. (1984) at the McLaren Mine in the Beartooth Mountains in southwestern Montana. They found that plant density, cover, and productivity did not increase with repeated application of fertilizer over time. They also found decreased productivity and low establishment of native plants. Walker (1982) evaluated the response of native and agronomic species to three fertilizer regimes including a control and two rates of ammonium nitrate (26-13-0) at the Lake Louise ski area (2300 m ASL). The rate of fertilizer N did not improve seedling establishment, however after three growing seasons, ground cover was significantly greater for the high N than the low N and no N treatments. In a similar study near Banff (2290 m ASL) conducted by Sadasivaiah and Weijer (1982), results indicated that applications of fertilizer at the time of seeding had no effect on seedling establishment of native and agronomic species. Fertilizers resulted in an increase of native species biomass but did not influence tillering ability.

Macyk and Pojasok (1995) reporting on research in the alpine near Grande Cache, Alberta (2100 m ASL) also found that fertilizer addition did not increase seedling establishment but did increase plant biomass and accelerated seed head formation and seed development. Urbanska (1986) indicated that alpine plants do not require extensive fertilizer application because their life strategy is based on growth efficiency rather than high growth rates.

Numerous studies evaluating the effectiveness of fertilization for revegetation in the subalpine have been completed (Berg & Barran, 1978; Errington, 1979; Macyk, 1985; Takyi & Islam, 1985; Ziemkiewicz, 1982). Nitrogen deficiency was the most common soil fertility problem encountered in revegetation activities in the subalpine (Berg & Barrau, 1978; Macyk, 1985; Takyi & Islam, 1985). Takyi and Islam (1985) reported that discontinuation of maintenance fertilizer application for two seasons resulted in a significant decline in plant cover and production on infertile calcareous mine spoil in the subalpine in Alberta. Ziemkiewicz (1982) also found that withdrawal of annual fertilization resulted in a major decline in shoot and root production on reclaimed coal mine spoil in the subalpine (2100 m ASL) in southeastern British Columbia. Authors for both studies suggested that these reclaimed areas may require long periods of maintenance fertilization.

Monitoring fertilizer requirement has been one component of a research program underway for the past 23 yr in the subalpine (1700 m ASL) near Grande Cache, Alberta (Macyk et al., 1995). During the initial stages of the project, the introduced grasses and legumes showed a marked response to the application of fertilizers to the extent that fertilized plots produced 10 to 20 times more dry matter than the unfertilized plots. Time and annual monitoring of growth resulted in the development of an appreciation of species suitability and desirability and stand composition in addition to fertilizer requirement. With time and the withholding of fertilizers, alfalfa increased its share of the ground cover while the grasses, which tended to comprise a major portion of the initial cover in a mixed stand, declined in vigor. The N-fixing ability of the alfalfa continues to assist in supporting the vegetation cover, which now has a significant component of natives. Based on the long-term observations, a general fertilization strategy was prepared for the area. It was recommended that fertilizers be applied at the time of seeding (Year 1) and again the following year (Year 2). For areas seeded to mixtures comprised of grasses only, refertilization should occur in Year 3 to maximize establishment and then again in Year 6. For areas where legumes such as alfalfa are included in the mixture, the vegetation cover may require refertilization in Year 5 with no further applications required thereafter.

Slow-release fertilizers also were investigated as part of the research and found to be useful, however cost was considered to be a limiting factor in operational use at that time (Macyk, 1975).

7. Transplanting Individual Plants

Transplanting individual plants, although labor intensive and therefore expensive, has proven to be an effective method of revegetation with generally high survival rates. Transplanting may be the most effective revegetation technique available on particularly difficult sites where more conventional techniques are not practical. Results have been reported by Brown and Johnston (1976) Brown et al. (1978), May (1976), May et al. (1982), Willard (1976), Webber and Ives (1978), Willey (1982), Walker and Harrison (1986), Urbanska (1986), and Walker et al. (1977). Conclusions from the research indicated species with fibrous roots perform better than plants with rhizomatous roots that in turn did better than plants with corms. Alpine plants produced in greenhouse containers were successfully transplanted in the field, suggesting a potential for large-scale production. It also was noted that tussocks of some alpine grasses could be subdivided into single tillers and transplanted.

8. Transplanting Sod

Transplanting sod or plant cover enables plants to become quickly established which is important in the alpine and subalpine because of the short growing season. Almost all researchers involved in revegetation work have evaluated the technique. Brown et al. (1976), Marr et al. (1974), Walker (1982), Walker and Harrison (1986), and Willard (1976), reported results they achieved using the technique for reclaiming pipelines in the alpine tundra, surface mined areas and alpine hiking trails. Pipeline reclamation is described in Fedkenheuer (2000, see Chapter 34). Good results require management practices that are similar to those for the use of sod in landscaping. Prompt placement in the reclaimed area is critical and placement must be in a manner that will not result in the edges drying out. Transplanting sod may have the disadvantage of the damage caused to the donor area, however most sod is likely to come from locations that will be disturbed during the course of operations in an area.

9. Natural Invasion

Natural invasion of disturbed areas in the alpine and subalpine will occur over time and has been documented in many areas. The physical and chemical properties of the exposed spoil or soil and the site-specific climatic conditions will determine the nature and extent of the invasion. In some locations, especially those that are exposed to direct wind and have low moisture-holding capacity, the invasion process occurs very slowly.

Natural invasion of previously revegetated sites also occurs, again depending on site-specific conditions. This invasion is the result of seed spreading from adjacent undisturbed areas and/or the result of incorporation of seed and vegetative material during soil salvage operations, and the resultant germination of seed or sprouting of vegetative material following soil replacement.

Van Zalingen et al. (1988) completed a study to evaluate the factors affecting native species invasion at a subalpine mine site that had been revegetated with agronomic species in the vicinity of Grande Cache, Alberta. Following mining in the early 1970s, the area was regraded, cover soiled, and seeded to smooth brome *(Bromus inermis* var. Carlton), creeping red fescue *(Festuca rubra* var. Boreal), timothy *(Phleum pratense* var. Climax), crested wheatgrass *(Agropyron cristatum* var. Fairway), alfalfa *(Medicago sativa* var. Rambler) and alsike clover *(Trifolium hybridum).* The measurements at 220 sample points included the dependent variable of percentage cover for each native species identified within Daubenmire (Daubenmire, 1959) frames. Independent variables included percentage slope, aspect, cover soil depth, fertilization and seeding treatments, coarse fragment content, distance from nearest undisturbed area, and distance from the nearest upwind seed source. A total of 60 native grasses, legumes, forbs, and shrubs were identified. Ranking of independent variables indicated that coarse fragment content was the most important variable contributing to native species cover. Thinner cover soil mantles on sites with higher coarse fragment contents likely decreased competition from the seeded introduced species. The coarse fragments also created favorable microsites for the native species providing a variable ground surface with depressional areas of moisture and seed collection.

Northwest vs. southeast aspect and distance from the nearest westerly undisturbed area ranked second, followed by percentage cover of alfalfa. Percentage slope and soil depth ranked relatively low. These observations suggest that revegetation can be planned and managed to include available native seed in the original seed mix as well as the expectation that natives will invade or encroach on their own depending on the competitive abilities of the introduced species and site characteristics.

VII. CONCLUSIONS

Development, including industrial and recreational pursuits, will expand in the alpine and subalpine regions of North America. Demands to extract the minerals and fossil fuels contained in these areas also are accelerating. Demands for expanding recreation access and facilities to satisfy year-round activities also are increasing. General techniques for revegetation practice have been developed and great strides have been made in selecting, testing, and development of native species. Although additional research is required to respond to specific problems, significant progress has been made over the past two decades. The number of suitable species and amount of seed available commercially also has increased significantly.

Further research is needed to develop a better understanding of successional processes on disturbances in these areas, which implies the need for long-term studies. In these areas of harsh climate and minimal soils, this means studies in excess of 10 yr. Some long-term studies are needed because decisions relative to operational practice are often made on short-term results. It is likely that much of the information required is, and will become available, by continuation of studies already in place and supplemented by carefully designed studies to augment existing information and fill the current gaps. It also is clear that a significant amount of valuable research results exist but are not readily available in the literature.

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