

THIRTY YEARS OF RECLAMATION RESEARCH IN THE ALPINE AND SUBALPINE REGIONS IN ALBERTA, CANADA¹

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Abstract. The Alberta Research Council, Inc. (ARC) has conducted a surface coal mine reclamation research program in association with the operations of Smoky River Coal Ltd. near Grande Cache, Alberta since 1971. The main objective of this long-term study was to develop and refine cost-effective methods of establishing a self-sustaining vegetation cover that is in harmony with adjacent undisturbed areas.

Soil handling practice development involved the completion of soil surveys and development of soil salvage and replacement strategies in these regions where salvageable soil materials are minimal to non-existent. Plot studies to determine the suitability and adaptability of various introduced and native grasses and legumes as well as fertilization trials were established and monitored annually. In the early 1970's the lack of native seed necessitated the use of introduced species for large scale operational revegetation work in the subalpine region. Long-term monitoring results indicated that desirable introduced species will thrive and reproduce at these elevations and that native herbaceous species as well as trees and shrubs will invade the revegetated areas. Revegetation research activities in the alpine involved the use of native grasses and legumes indigenous to the area. Container and bare root conifer seedlings and cuttings of deciduous species were utilized initially to establish trees and shrubs in the subalpine. Direct seeding has also proven to be a viable method for establishment of trees and shrubs in the subalpine. Automated climate monitoring stations were installed at different elevations at three locations in the study area yielding data that support the conclusion that climate is the most limiting factor to reclamation success in the subalpine and alpine regions.

Research results were transferred to the operational scale throughout the term of the study. Recommendations regarding appropriate reclamation practices for the regions including soil salvage and replacement strategies, revegetation techniques and successional processes have been developed.

Additional Key Words: cover soil, native species, introduced species, climate monitoring, direct seeding.

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Introduction

Industrial development and recreational use are rapidly expanding in the subalpine and alpine regions of North America (Macyk, 2000a). 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). 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 (Macyk, 2000a).

In 1972, McIntyre Porcupine Mines Limited, the original mine operator in the Grande Cache area, commissioned the Alberta Research Council, Inc. (ARC) to undertake a reclamation research study. Coal production from the original No. 8 Mine began in June 1971, and reclamation research followed. In 1976, a similar study began at the No. 9 Mine (Figure 1). In 1992, a project to evaluate the potential for revegetating the mined land in a proposed No. 12 Mine in the alpine was initiated (Figure 2). The research program continued in cooperation with Smoky River Coal Limited until March 2000.



Figure 1. Spoil piles in the subalpine.



Figure 2. Surface mining in the alpine.

When the ARC undertook the study, reclamation research was in its infancy in Alberta. Techniques used elsewhere at the time, primarily in the eastern United States, were not applicable in Alberta. Legislation pertinent to reclamation in Alberta was not formally in place until the Land Surface Conservation and Reclamation Act of 1973 and the Coal Policy of 1976 (Macyk, 2000b).

It is difficult to summarize 30 consecutive years of work in one paper. As a result, this paper provides a summary of the observations along with selected data. Readers interested in the data related to the various topics discussed are referred to the annual reports prepared by the author as well as published papers including Macyk (1985), Macyk and Widtman (1987), Macyk et al. (1989), and Macyk et al. (1998). Individuals interested in recommendations regarding reclamation practice in the alpine and subalpine are referred to Chapter 21 – “Reclamation of Alpine and Subalpine Lands” prepared by the author for the book entitled “Reclamation of Drastically Disturbed Lands” published as Agronomy Monograph No. 41 by the American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America.

Objective

The objective of the study was to develop and implement cost-effective techniques for reclamation that meet the requirements of regulatory agencies. Initially, emphasis was placed on

determining methods of establishing a long-term vegetation cover that is in harmony with adjacent undisturbed areas by:

- Characterizing unmined and reconstructed soils and evaluating their suitability for reclamation;
- Determining suitable grasses and legumes for establishing a protective vegetation cover on reclaimed areas to minimize erosion; and,
- Determining the nutrient requirements for maintaining a viable vegetation cover.

Because this study continued for a relatively long time, new objectives were added as additional needs were identified. Modifications were made to the conclusions and recommendations developed as the length of record increased and more data became available. The long-term monitoring allowed for the development of recommendations for operational reclamation practices in the alpine and subalpine.

Materials and Methods

Soils

The unmined soils in the No. 8 and No. 9 Mine areas were dominantly Luvisolic (Boralfs) and Brunisolic (Dystrochrepts and Eutrochrepts) (Canada Soil Survey Committee 1978). The depth of salvageable material overlying bedrock ranged from 10 cm to 1 m. The unmined soils were moderately to slightly acid, medium textured, and had low levels of available plant nutrients, especially nitrogen and phosphorus.

Soil salvage was an integral part of the materials handling program associated with the mining operation. Following the removal of merchantable timber, the soil overlying consolidated bedrock was removed in one lift, incorporating a minimum amount of coarse fragments. The soil materials were stockpiled for future use. Because the surface or organo-mineral horizons were minimal or nonexistent, and the sola varied in thickness, segregation or selective handling of soil materials was not considered. Soil material was replaced on the spoil surface following the removal of overburden and coal and subsequent backfilling and grading.

Vegetation Establishment

The land use goal of reclamation in the area was to develop a landscape that has equivalent productive capability (Macyk 2000b). Overall the intent was to re-establish a diverse vegetation cover that is dominantly forest with a capability for wildlife use and a cover that provides erosion control.

In May 1972, vegetation work in the subalpine was initiated by establishing three research plot areas with slopes ranging from 0 to 40°. The three locations included 60 individual 6 m x 9 m plots to determine the suitability of 30 different agronomic or introduced grasses and legumes (Table 1). Over the years a total of 43 different plot areas were established to assess revegetation in the subalpine portion of the overall mined area.

The experimental site in the alpine was established in July 1992 and located outside the boundary of the area to be mined in order to preserve the integrity of the site. The two plot areas were located on a gentle southwest facing slope, representing the most difficult slope position to reclaim in this region.

Two different surface or growth medium material including “cover soil”, or the surface material, and the “rock spoil” material were used. The cover soil plot area was constructed by first removing the surface soil layer (12 to 18 cm) and then excavating and mixing the underlying spoil material to a depth of about 1.5 m. The mixed spoil was leveled and the cover soil replaced on the spoil surface (Macyk et al., 1998).

The rock spoil plot area was constructed by excavating and mixing the weathered rock material to a depth of about 1.2 m. There was no surface soil present in the area prior to disturbance resulting in a growth medium comprised of fragmented rock and the associated fines. Both the “cover soil” and “rock spoil” materials are typical of the area and are representative of the reconstructed surface that occurs following surface mining activities. A total of 18 plots (4 m x 8 m) were established at each of the two locations. The rock spoil plot treatment group was located about 300 m north of the cover soil plot treatment group. A wire mesh fence approximately 2 m in height was constructed at each of the two plot areas to protect the plots from all-terrain vehicle traffic (Macyk et al., 1998).

Table 1. Introduced Grasses and Legumes.

Grasses	Legumes
Brome grass: <ul style="list-style-type: none"> • Carlton • magna • polar 	Alfalfa: <ul style="list-style-type: none"> • beaver • chimo • drylander • Rambler • roamer
Creeping foxtail	Alsike clover
Creeping red fescue: <ul style="list-style-type: none"> • Arctared • Boreal • Erica 	Birdsfoot trefoil: <ul style="list-style-type: none"> • Leo
Durar hard fescue	Sweet clover
Intermediate wheatgrass	White clover
Kentucky blue grass	Vetch: <ul style="list-style-type: none"> • Spring • crown
Meadow foxtail	
Nugget blue grass	
Perennial rye grass	
Pubescent wheatgrass	
Redtop	
Rough fescue	
Russian wild rye (Sawki)	
Slender wheatgrass	
Streambank wheatgrass	
Tall wheatgrass	
Timothy	

In addition to the effect of the different surface material characteristics, species type was the other major variable included in the experiment. Grass seed was obtained from native plant researchers at the Alberta Environmental Centre and a commercial seed supplier. The species included alpine bluegrass (*Poa alpina*) seeded at 110 g/plot, Highlander slender wheatgrass (*Agropyron trachycaulum*), Mountaineer broadglumed wheatgrass (*Agropyron violaceum*), and sheep fescue (*Festuca ovina*) each seeded at 175 g/plot.

Plot seeding was completed September 1 and 2, 1992. Raking was completed immediately after the seeding of each plot. Selected plots were fertilized with the equivalent of 125 kg/ha of 35-15-0 in June 1993. The plot treatments included three replicates of each treatment at each of the two locations. The control and sheep fescue treatments were not replicated due to space limitations. Eighteen plots were established at each of the two locations.

Native Species

The use of native species in reclamation in these areas was addressed early in the study. In 1972, seed from native species was not available commercially. Consequently, seeds from the following species were collected in the undisturbed portions of the mine area and subsequently cleaned and planted:

- silky locoweed (*Oxytropis sericea*)
- showy locoweed (*Oxytropis splendens*)
- alpine hedysarum (*Hedysarum alpinum*)
- lupine (*Lupinus* spp.), and
- hairy wildrye (*Elymus innovatus*).

In 1986, factors affecting native species invasion were evaluated at the No. 8 Mine (Van Zalingen et al., 1988). Sampling point locations were predetermined by randomly applying a 60 m interval grid pattern to a 1:3000 aerial photograph of the site. Grid intersections were taken as individual sampling points. At each of the 220 sample point locations, a 10 m tape was laid out due west and 20 x 50 cm (Daubenmire) frames were placed at the 2, 4, 6, 8, and 10 m points. Visual estimates of percent cover (aerial) were recorded for each species present within the frames. Additional data recorded for each sampling location included percent slope, aspect (degrees), and a visual estimate of coarse fragments and coal waste present.

Data used in statistical analysis included that collected on the site and additional data available from previous studies by ARC, including fertilization and seeding treatments, cover soil depth, distance from the nearest undisturbed area, and distance from the nearest upwind disturbed area. The statistical analyses of data consisted primarily of covariance analyses. Dependent variables were percent cover values for native species identified within Daubenmire frames. Independent variables included percent slope, aspect, cover soil depth, fertilization and seeding treatments, number of times fertilized, number of times seeded, coarse fragment rating, coal waste rating, distance from the nearest undisturbed area, and distance from nearest upwind seed source. Coarse fragment and coal waste ratings were treated as class variables.

Tree and Shrub Establishment

The study assessed the growth of native trees and shrubs on reclaimed land relative to meeting the objective of establishing a long-term cover in harmony with the surrounding area. As seedlings suitable for planting above an elevation of 1100 m ASL were unavailable, a cone collection program was undertaken. Seedlings of lodgepole pine (*Pinus contorta* var. *latifolia*), engelmann spruce (*Picea engelmannii*), and white spruce (*Picea glauca*) were reared in a greenhouse. Different sizes and types of containers were used to determine those containers most suitable for production of seedlings for planting in reconstructed soils and to assess the relative costs associated with seedling production.

Branch cuttings of willow (*Salix* spp.) and balsam poplar (*Populus balsamifera*) and root cuttings of aspen (*Populus tremuloides*) were rooted in the greenhouse. Direct planting methods were also used for willow cuttings. Most of the materials were planted at reclaimed sites with an established grass, or grass and legume cover.

Climate Monitoring

Climate monitoring began in 1973 with the measurement of rainfall and air and soil temperatures, and continued until March 2000. The types of equipment used and the number of parameters measured changed with time as the technology improved and monitoring locations were added as mining advanced. The parameters measured included air temperature, soil temperature, rainfall, wind speed, wind direction, relative humidity, solar radiation, and soil

moisture. These parameters were measured at four different locations representing elevations ranging from 1000 m to 2100 m ASL. Figure 3 illustrates a fully instrumented monitoring site.



Figure 3. A fully instrumented climate monitoring site in the subalpine.

Initially Campbell Scientific CR21 (Campbell Scientific Inc.) units were installed to monitor soil and air temperature. Subsequently, Model 824 and Model 900 Easylogger units (Omnidata International Inc.) were used. Rainfall was measured with the Taylor Clear-Vu rain gauge (Taylor Instrument, Sybron Corporation) and tipping bucket units. Soil moisture was measured by use of SM898 Beckman soil moisture blocks. The LICOR LI-200 SB pyranometer sensor was used to measure solar radiation and the Vaisala HMP IIIA humidity sensor was used to measure relative humidity. Wind speed and direction was measured by use of the Young Model 05102 wind monitor.

Results and Discussion

Climate Monitoring Data

The climate monitoring program has generated a large database that is an important component of reclamation planning and long-term site management in the alpine and subalpine. Understanding the distribution of rainfall during the growing season and the variability between seasons has helped in the development of recommendations for the optimum time for seeding

and planting and the periods when less than optimum rainfall, and ultimately, soil moisture conditions are likely to prevail. Figure 4 illustrates the variability in growing season precipitation totals for 1973 to 1999 inclusive at the No. 8 Mine located in the subalpine at an elevation of 1400 m ASL. For 10 of the first 13 years of record, the rainfall was below the calculated average. For the latter 14 years, rainfall was above average for six years.

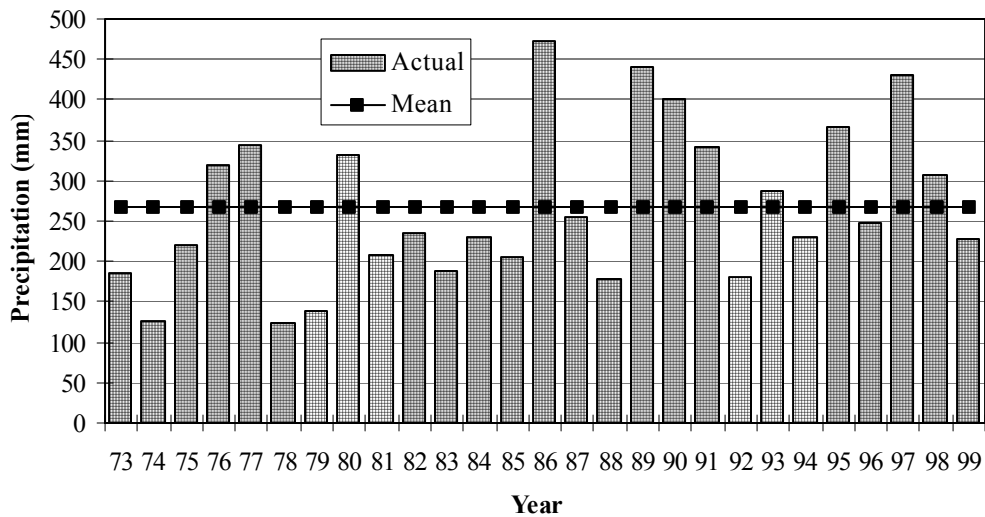


Figure 4. Growing Season Rainfall at No. 8 Mine from 1973 to 1999.

The precipitation total for a growing season is important, however distribution of rainfall throughout the season is critical for effective plant establishment and growth. The records have indicated that very often the distribution of rainfall was somewhat less than effective for good plant establishment and growth and the intensity of precipitation was such that a major portion of the water was lost through runoff. For example, greater benefit occurs from the occurrence of 10 mm of rainfall over a period of 20 hours than in a period of 20 minutes. Rainfall events with the occurrence of 1 mm per minute for a minimum of 10 consecutive minutes have been recorded at least once annually. Rainfall intensity data has provided some insight into the ability of the reconstructed soil to absorb water or allow infiltration to occur and the potential for runoff and erosion to occur.

Detailed air and soil temperature data are available for the alpine and subalpine locations. This has allowed for determination of frost-free and killing frost-free periods as well as determination of degree-days that accumulated. Degree-days above 5°C provide an estimate of the growth stage of a plant based on temperature measurements. For each degree above the base

temperature of 5°C, one degree-day accumulates. For example, on a day with an average temperature of 15°C, a total of 10 degree-days accumulate. The agricultural or crop production area of Alberta has a range of 2200 to 2500 degree-days.

In summary, the alpine site at 2100 m ASL had mean growing season temperatures of 5° to 8°C, a frost-free period of 28 days to 64 days, and a mean total of 400 growing season degree-days. One of the subalpine sites at 1750 m ASL had average growing season temperatures ranging from 9° to 12°C, a frost-free period of 45 to 110 days with an overall average of 85 days, and a mean total of 900 growing season degree-days.

During the first year of the project, when plot establishment was underway in the subalpine, surface soil temperatures in excess of 50°C were recorded for bare soil materials when air temperature was greater than 25°C. Relatively dark soil materials comprised of soil and coal fines reached temperatures in excess of 55°C. Surface temperature of 45° to 50°C can cause stem girdle of tree seedlings, particularly if soil moisture levels are low (Day, 1963). Soil temperature data has provided the basis for decision making regarding locations where planting of tree seedlings should not be undertaken due to high surface soil temperatures.

Persistent and strong winds are typical in the alpine and subalpine. During the initial establishment phase of the study it seemed that the wind blew constantly and on many days disrupted normal field activities. Macyk and Pojasok (1995) reported average monthly wind speeds of 30 to 40 km/hr during the October to March period and 20 to 30 km/hr 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/hr. Similar measurements at the subalpine site (1750 m ASL) indicated that maximum velocities in excess of 70 km/hr occurred for at least 10 days per month. The highest velocity recorded at this subalpine site was 148 km/hr.

Wind speed and direction data contributed to revegetation strategies that take into account the dynamics of native seed dispersion and the effects of snow cover removal in some areas, and the related need for adequate ground cover to protect susceptible species such as newly planted tree seedlings.

Soil Salvage and Replacement

A soil survey with relevant interpretations was completed for each of the mine areas prior to disturbance of the site. This data provided the information to assess the suitability or quality of

the different soils and to develop salvage and replacement plans. Approximate volumes of soil material available for salvage and subsequent replacement were determined.

Practical soil salvage guidelines were developed along with a field manual describing the procedures that should be followed to ensure that the limited soil resource available is managed effectively. The guiding principles are:

- Soil quality is more important than soil quantity;
- The salvage process involves the removal of suitable soil material from as large an area as possible rather than removal of suitable and less suitable material from smaller areas to achieve the required volume needed for replacement;
- Coarse fragment or rock content in the salvaged soil should be minimized. It is recognized that it is impossible to eliminate them completely due to the nature of the soils in the area; and,
- The maximum slope that allows for the efficient use of equipment for soil salvage is about 27 degrees.

Selective handling of the soil material was not practiced due to the generally shallow nature of the soils and the variability in thickness over short distances (Figure 5). The slope angle also restricted the total area from which the soils could be effectively and safely salvaged. Figure 6 illustrates an area where 25 cm of suitable soil material was available, but the slope angle of 38 degrees precluded any salvage operations.



Figure 5. Shallow soils typical of the subalpine region.



Figure 6. Slope angle precludes any soil salvage operations.

Salvaging and replacing soils in areas to be mined and reclaimed resulted in a reconstructed surface soil horizon that reflected a blending of soil characteristics found in pre-mining soil horizons. The reconstructed soils that were developed did not duplicate the soils that had existed before disturbance. The mining process most dramatically altered the physical properties of the soils. The data indicated that, compared with unmined soils, reconstructed soils had a coarser texture, higher pH (neutral rather than acidic), and lower levels of available plant nutrients.

The thickness of the replaced cover soil layer was dependent on the amount available prior to salvage and the efficiency of the salvage and replacement operations. Throughout the life of the mining operations the cover soil was replaced in a manner that resulted in optimum revegetation of an entire area. As a result, the replaced thickness varied from about 10 cm to 30 cm.

The silt loam texture and low levels of organic matter resulted in a crusting problem, which has a direct bearing on infiltration capacity and processes such as runoff and erosion. Infiltration tests indicated that the undisturbed soils had considerably higher infiltration rates than the reconstructed soils. Although these reconstructed soils have some limitations, with proper management they are critical in achieving reclamation success. Figure 7 illustrates a reconstructed soil, two years after placement of 20 cm of cover soil over rock spoil. Figure 8 illustrates a similar soil 27 years after cover soil placement. Extensive rooting has occurred despite the fact that this area has had only a grass cover throughout the period since the area was reclaimed.

Vegetation Establishment

An initial vegetation cover was established on the subalpine sites to minimize the potential for erosion and to assist in the restoration of the reconstructed soil (Figure 9). Because there was no supply of native materials available at the time, introduced species were used resulting in a uniformly established cover one year after seeding (Figure 10). An initial concern was that these introduced species, in particular alfalfa, would not adapt or survive in the subalpine. However, most of the introduced grasses and legumes seeded initially have survived and continue to thrive. With time and withholding of fertilizer, alfalfa increased its share of ground cover while grasses, which were the major component of the cover in a mixed stand, declined in vigor. Several recommended seed mixtures and seeding rates appropriate for different slope aspects (moisture

regimes) were developed. Figures 11 and 12 illustrate the change in vegetation cover that occurred in 25 years in an area that was initially seeded to a mixture of grasses and alfalfa.



Figure 7. Reconstructed soil two years after placement of 20 cm of cover soil.



Figure 8. Reconstructed soil 27 years after cover soil placement.



Figure 9. The first plot area established in the subalpine in June, 1972.



Figure 10. Introduced species became well established one year after seeding.



Figure 11. Grass cover established one year after seeding (1975).



Figure 12. Diverse vegetation cover that has evolved 25 years after initial seeding.

The seed of the native grasses and legumes collected in the undisturbed adjacent to the subalpine mine sites had relatively low germination rates. For example, the germination rate for locoweed was 70% while it was only 15% for the alpine hedysarum. Conversely, the plot seeding done with commercially available native seed at the alpine site in September 1992, resulted in excellent germination, emergence (Figure 13), and growth (Figure 14) in both the rock spoil and cover soil plot areas.



Figure 13. Grass emergence in the rock spoil material.



Figure 14. Growth of a variety of native grass species in the cover soil plots.

The application of fertilizer to the alpine plots in 1993 resulted in increased germination and enhanced growth at both plot areas with a more visible impact at the rock spoil site than the cover soil site. This was expected since the cover soil material initially had higher natural fertility levels than the rock spoil. The cover in the fertilized plots had greener, larger, and generally more lush plants (Macyk et al., 1998). In comparison, the plants in the unfertilized plots were shorter, more spindly (thinner), and slightly chlorotic in appearance. In addition to

the more enhanced growth at the rock spoil plots, the fertilizer also had a direct bearing on plant maturity. This indicated an earlier start to plant function and growth in the spring and/or more rapid progression of plant development during the growing season. The growth at the cover soil plots was quite evident in 1993 with lesser impact in 1994 and in subsequent years. This was expected as the initial fertilizer application rates were relatively low and plant uptake and losses due to leaching would eventually deplete the nutrients added. Observations in 1999 indicated that the fertilized treatment did not exhibit better plant vigour or cover density than the not fertilized treatments, confirming that the initial effects of fertilization had diminished over the 5 seasons since it was initially applied. These results suggest that an initial fertilizer application will enhance initial vegetation establishment and that subsequent applications will not likely be required.

In 1986, 60 unseeded species, including 8 native legumes, were identified at the No. 8 Mine subalpine study site. Statistical analyses were undertaken to assess the parameters measured, and these parameters and variables were ranked to determine their relative importance.

The distance from the nearest westerly undisturbed area significantly influenced the distribution of native species in the area. Except for moss, all native species exhibited a decline in percent cover with increasing distance from the nearest westerly undisturbed area. The independent variables were ranked in order of importance, as follows:

- coarse fragment rating of the reconstructed soil;
- northwest versus southeast aspect and distance from the nearest westerly undisturbed area;
- percent cover of alfalfa;
- percent slope; and,
- soil depth.

Invasion or encroachment of native species into the plot areas at the alpine site has been documented since the time that the plots were established. The rock spoil plots had an overall mean of 187 plants per plot compared to 123 plants per plot in the cover soil plots in 1999. This difference between the two areas or materials can be attributed in part to the fact that the grass cover is more dense in the cover soil plots resulting in less germination sites for invading natives. Also, many of the species identified appeared to have a preference for the rock spoil material and its associated microclimate.

Tree and Shrub Performance

The discussion of tree and shrub establishment and performance pertains to the subalpine region. Trees and shrubs were established successfully and thrive in areas initially seeded to grasses and legumes. Seedlings, growing in association with alfalfa, appeared healthier and more vigorous than those growing in association with grasses. The practice of planting seedlings in grassy areas was questioned initially because of the expected competition for moisture. However, the protection afforded to the seedlings 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 factors dictate that some form of protection for the young seedlings is critical in this region.

Two years after initial planting the overall survival rate was 8 percent for conifers planted in areas with no other cover and 58 percent in areas with a grass and legume cover. Container grown conifer seedlings were superior to bare root stock in the context of survival and growth rate (Macyk and Widtman 1987). Five years after planting, the container grown engelmann spruce had a survival rate of 58 percent compared to 46 percent for the bare root. The container grown pine had a survival rate of 52 percent compared to 35 percent for the bare root.

Survival rate increased with increasing size of container. The largest size of container utilized provided approximately eight times the volume of rooting medium than the smallest size utilized. The larger container allowed the seedling a better opportunity to develop a more effective root mass in the more desirable rooting material. One of the disadvantages of the larger size container seedlings was the requirement for planting holes to be at least 18 to 20 cm deep.

The rate of growth of trees planted in the reclaimed area compared to seedlings in the adjacent undisturbed areas was measured from 1983 to 1999. Figure 15 compares the growth of lodgepole pine on reconstructed and undisturbed soils and figure 16 provides a similar comparison for the engelmann spruce. The data indicate that in the initial years after planting the seedling growth was better in the undisturbed than the reclaimed areas. About six years later, as the trees became better established, the trend reversed and continued throughout the term of measurement. This could in part be due to the lower annual rainfall amounts that occurred in several years between 1984 and 1990 (Figure 4). The reconstructed soil areas offer the advantages of an open canopy and increased light and potentially higher levels of available soil

nutrients, however these areas are also more exposed to wind. Figures 17 and 18 illustrate the growth achieved by engelmann spruce and lodgepole pine twenty-three years after planting.

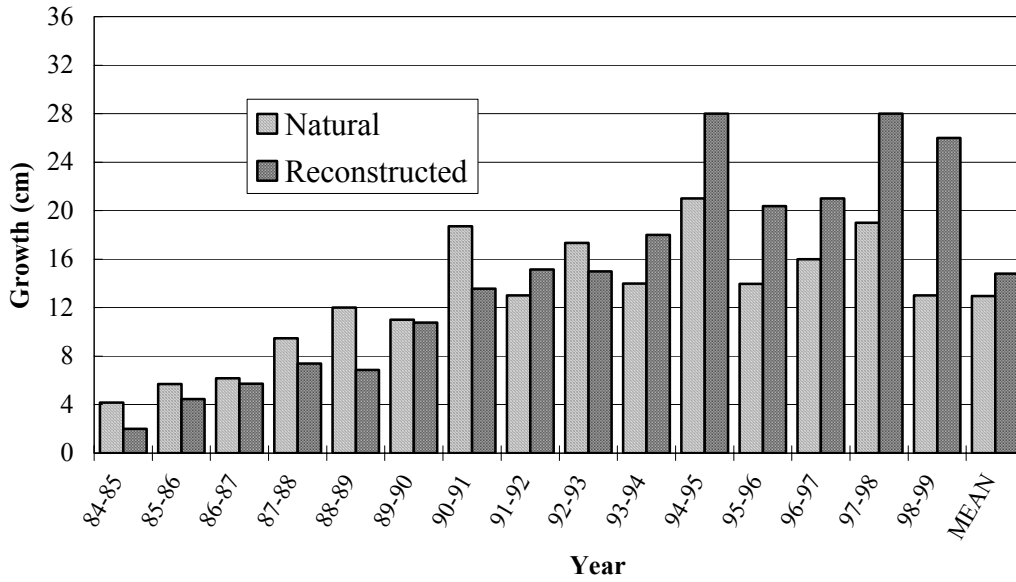


Figure 15. Annual and Mean Annual Growth of Lodgepole Pine on Reconstructed and Undisturbed Soils.

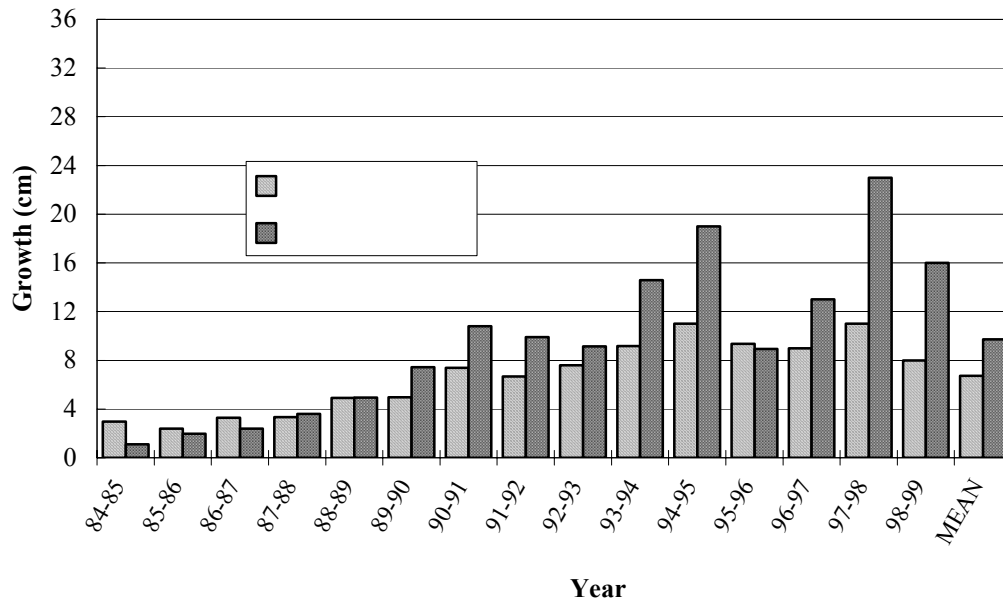


Figure 16. Annual and Mean Annual Growth of Engelmann Spruce on Reconstructed and Undisturbed Soils.



Figure 17. Engelmann spruce 23 years after planting.



Figure 18. Lodgepole pine 23 years after planting.

A number of factors led to the initiation of direct seeding trials as a means of tree and shrub establishment in the area. It became apparent that some of the seedlings that demonstrated poor growth had limited root egress. Furthermore, frost heaving of some of the container seedlings resulted in the exposure of the upper root mass surrounded by peat from the original container above the soil surface. As a result, the seedlings eventually died.

The problems described above combined with the difficulty in planting bare root and container seedlings at the site, along with the cost of production and planting, resulted in a desire to consider alternative methods for tree and shrub establishment.

Observations in the area indicated that spruce, pine, alder, willow, and buffaloberry were becoming established in significant numbers by natural means in the area. This implied that direct seeding might be a viable technique for tree and shrub establishment. A fall seeding program using lodgepole pine seed was completed in 1983 followed by spring and fall programs in 1984 and 1985. Seed of spruce, pine and alder were used in the 1984 and 1985 seeding programs. The results indicated that the pine germinants outnumbered the spruce for both spring and fall seeding and that fall seeded pine resulted in a 4 to 10 fold increase in germinants when compared to spring seeded pine. Figures 19 and 20 illustrate pine 4 years and 12 years after seeding. Figures 21 and 22 illustrate alder 1 year and 13 years after seeding.

The results obtained indicated that direct seeding can be a viable alternative to planting seedlings in some locations.



Figure 19. Lodgepole pine 4 years after seeding.



Figure 20. Lodgepole pine 12 years after seeding.



Figure 21. Alder one year after seeding.



Figure 22. Alder thirteen years after seeding.

Conclusions

Reclamation efforts in the alpine and subalpine can be successful provided that appropriate procedures are utilized and a realistic time frame is adopted to achieve the objectives. Good soil handling practices, selection of suitable seed and plant materials, combined with an understanding of the influence of climate and the need to plan according to site specific conditions will result in the establishment of diverse plant communities and allow for different land use options.

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