Factors affecting the native species invasion of a reclaimed subalpine minesite near Grande Cache, Alberta

by Sylvia Frances Van Zalingen

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Land Rehabilitation
Montana State University

Abstract:
Reclamation specialists in Canada and the United States have debated the utility of agronomic versus native species in mined land reclamation. Agronomic species are generally • readily available, easily established and inexpensive, while native species may be more viable on particularly harsh sites. Agronomic species are frequently heavily dependent on agricultural treatments, while native species are often slow, difficult, and expensive to establish.

Smoky River Coal Ltd., in cooperation with the Alberta Research Council, decided in the early seventies to use agronomic species in the revegetation of their Number 8 Mine site located north of Grande Cache, Alberta. Good coverage of the subalpine site by agronomic species was achieved. Since that time, researchers from the Alberta Research Council have noticed a gradual increase, in native species coverage on the minesite. This study was initiated to determine the nature of factors involved in the invasion. The primary objective was to identify and rank factors significantly affecting the native species invasion.

Data collection involved cover estimations at preselected sampling locations. Covariance analyses were conducted to identify variables significantly affecting invasion by native species.

Analyses indicated that significant variables included coarse fragments, aspect, distance from the nearest upwind seed source, alfalfa cover and slope. Independent variable rankings indicated that coarse fragment rating was the most important variable contributing to occurrence of native species. Aspect and distance from the nearest upwind- seed source ranked second.

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A thesis submitted in partial fulfillment
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of

Master of Science

in

Land Rehabilitation

MONTANA STATE UNIVERSITY
Bozeman, Montana

December, 1987

APPROVAL

of a thesis submitted by

Sylvia Frances Van Zalingen

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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ACKNOWLEDGEMENTS

I wish to thank the many people who provided assistance during the course of project planning, data collection, data analysis and thesis assembly. Dr. D.J. Dollhopf and the Alberta Research Council arranged the project, with the Alberta Research Council funding data collection. Dr. Frank Munshower, Dennis Neuman and Bob Rennick provided help in planning the data collection methods. Smoky River Coal Ltd. allowed me to work on their property. Terry Macyk, Zdenek Widtman and Faye Nikiforuk of the Alberta Research Council provided guidance and technical support during data collection. Kathy Hanford, Carol Bittinger and Dr. Richard Lund spent innumerable hours instructing me in the use of SAS and guiding me through the lengthy data analyses. Dr. Brian Sindelar provided 'food for thought' during the struggle through certain portions of the thesis. Finally, I would like to thank Ray Carrier for his invaluable assistance in use of various computer packages and for his patient moral support.

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ABSTRACT

Reclamation specialists in Canada and the United States have debated the utility of agronomic versus native species in mined land reclamation. Agronomic species are generally readily available, easily established and inexpensive, while native species may be more viable on particularly harsh sites. Agronomic species are frequently heavily dependent on agricultural treatments, while native species are often slow, difficult, and expensive to establish.

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INTRODUCTION

The Alberta Land Conservation and Reclamation Act of 1974 mandates that land disturbed by surface mining in Alberta be reclaimed to a level of productivity or usefulness at least equal to the level which existed prior to mining activities. Yet, both the Act and the ensuing 'Land Conservation Regulations' are relatively ambiguous regarding the nature of the plant communities to be developed on reclaimed sites. No mention is made of whether postmine vegetation should approximate premine vegetation in terms of species composition or diversity.

This absence of specific requirements provides both mining companies and regulatory agencies with great flexibility in determining appropriate revegetation plans on a site-specific basis. It has also created room for debate within the reclamation community regarding the utility of native versus introduced species. The debate has become particularly heated with regard to revegetation of high elevation areas in the Eastern Slopes of Alberta.

Smoky River Coal Ltd. (formerly McIntyre Mines Ltd.), in cooperation with the Alberta Research Council, reached a decision in the early seventies to use agronomic species in the revegetation of their Number 8 Mine. Location of the minesite is depicted in Figure 1. Despite criticisms that agronomic species were unsuitable for the harsh subalpine environment of the site, good coverage by these species was achieved (Macyk, 1985).

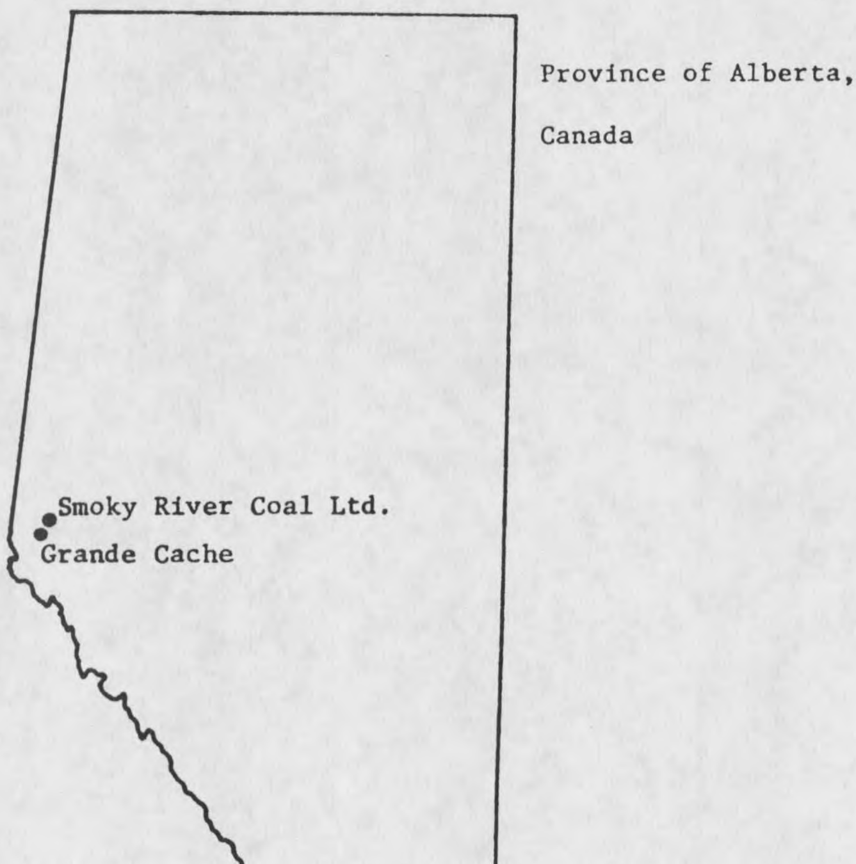

Figure 1. Location of Smoky River Coal Ltd..

During the years since the area was seeded, researchers from the Alberta Research Council have noticed a gradual increase in the number and extent of native species present on the minesite. Three 5 by 5 m plots were established in 1984 to give some initial indication of the extent of native species invasion (Macyk, 1984). Data from the plots indicated a general decline in native species populations with increasing distance from the undisturbed forest. In order to learn more about the factors involved in this native species invasion, the Alberta Research Council, in cooperation with Montana State University, agreed to fund additional research into the process.

The purpose of this study was to fulfill objectives of the Alberta Research Council in determining the nature of factors involved in the native species invasion.

Objectives of this study were to:

(1) Identify and rank factors affecting the areal extent and distribution of native species on the minesite.

(2) Provide recommendations for enhancing future native species invasions of similar disturbed areas.

LITERATURE REVIEW

Introduction

An invasion of native species will occur over time on any site which has been seeded to agronomic species. Potentially, such a site will revert to a near-native species composition (Hawk, 1973). The natural revegetation process appears to be multifactorial (Gibson et al., 1985). Specific management practices can alter the rate at which native invasion occurs (Hawk, 1973).

Use of competitive and well-adapted agronomic grass species can impede the rate of native species invasion (Johnson, 1981). Fertilization or other practices which enhance growth of agronomic species can have a similar effect (Hawk, 1973). Other factors potentially affecting invasions by native species include soil substrate conditions, distance from sources of native species propagules (Gibson et al., 1985), slope stability (Hawk, 1973), and aspect (Errington, 1975).

Soils

The influence of soils on postmine vegetative productivity and composition is associated with depth of topsoil and chemical and physical properties of topsoil and subsoil (Redente and Hargis, 1985; Rowell, 1981). Studies documenting effects of topsoil depth on revegetation success and vegetation composition have attained variable results (Biondini et al., 1984; Redente and Hargis, 1985). Biondini et al. (1984) were unable to find a significant pattern in vegetation composition as related to soil depth. Redente and Hargis (1985) found that total vegetation production tended to decrease as topsoil depth declined from 60 to 30 cm. Greater productivity levels at greater topsoil depths were attributed primarily to growth of perennial grasses and annual weeds. Perennial forbs and shrubs were virtually excluded on these sites.

Physical characteristics of postmine soils have been discussed by a number of authors (Martens and Nicholson, 1976; Ashby et al., 1982; Rowell, 1981; Johnson and Van Cleve, 1976). Rowell (1981) stated that physical characteristics of postmine soils in mountainous areas probably limit plant growth more than chemical or biological properties. Postmine spoils were characterized by Martens and Nicholson (1976) as being very coarse textured with low soil moisture retention capabilities.

They tended to be dark in color with high bulk densities and low cation exchange capacities.

High coarse fragment contents are common in spoils (and possibly soils) of minesites located in mountainous areas (Rowell, 1981). Rowell reported that coarse fragment contents less than 20 percent by volume may increase permeability and aeration of dense soils. He stated that higher coarse fragment levels will result in a reduction of soil moisture holding capacity and cause the proportion of soil available for root growth to become too small. Ashby et al. (1984) disagreed. They noted that coarse fragment contents as high as 45 percent by volume in near surface soils had no detrimental effects on yield of corn, pasture and trees.

Rock fragments affect chemical and physical properties of soils. Their effects on plant productivity are difficult to assess independently of other soil variables altered during mining and reclamation processes. Rock fragments affect soil temperature regimes, water absorption, aeration and surface area per unit volume of soil. Coarse fragments in mountainous areas may extend the growing season length by increasing soil temperatures early in the spring and maintaining higher soil temperatures through the summmer. Water frequently remains in scattered voids in the profile throughout the growing season.

It infiltrates readily into soils high in coarse fragments and is more readily available to plants because coarse fragments hold it at low tensions. Coarse fragments improve porosity and aeration in uncompacted minesoils. Despite reductions in surface area per unit volume of soil, rooting volume may be unaffected because rooting depth is frequently increased (Ashby et al., 1984).

Presence of organic matter in postmine soils will enhance structure forming capabilities of these soils (Cook et al., 1974). Positive attributes of soil organic matter were discussed by Brady (1984) and included improved soil moisture holding capacity and nutrient cycling. It is desirable to apply topsoil where possible and to minimize topsoil storage times. Topsoil application may ameliorate poor physical spoil characteristics such as dark color.

Soil and spoil chemical limitations in mountainous areas vary with the site. Topsoil application ameliorates some of the adverse chemical limitations, providing that it is available in sufficient quantities. But, Brown (1978) stated that it is possible to overcome adverse spoil conditions in alpine areas even in the absence of available topsoil. He cited use of chemical amendments such as lime, and the application of organic matter and fertilizers as possible means of achieving this.

Fertilization

Fertilization of high altitude sites is generally considered critical at or near the time of seeding to achieve successful vegetation establishment (Fyles et al., 1981; Johnson, 1980). Several authors were convinced that when agronomic species are seeded, repeated fertilization treatments will be required to achieve continued survival of these species (Fyles et al., 1981; Bell and Meidinger, 1977). Where mixtures of native and agronomic species have been seeded, there is little doubt that fertilizer applications provide agronomic species with a competitive advantage. Errington (1978) noted that within agronomic species mixtures, applications of fertilizer resulted in improved grass species growth at the expense of legumes.

Trials by Ledgard (1974) indicated that addition of fertilizers to areas of bare subsoil where herbaceous vegetation had been introduced frequently resulted in increased competition from previously established plants rather than promotion of seedling growth. Herbaceous cover growth was enhanced through minimization of initial fertilizer applications. Nitrogen fertilizer promoted rapid growth of fibrous rooted grasses (Ledgard, 1974). Doerr and Redente (1983) also reported that forb biomass was reduced by fertilizer applications. They attributed greater forb biomass on unfertilized plots compared to fertilized plots to a reduction in grass competition within unfertilized plots. They concluded that fertilizers reduced the time necessary for grasses to achieve high production levels at the expense of forb productivity.

In a study of a sagebrush - grass community in northwest Colorado, grass production increased with fertilization, while forb production declined and shrubs were unaffected (Redente et al., 1984). Increased forb production on unfertilized areas was attributed to decreased competition from grass species. It was suggested that if forbs are desired, fertilizer applications should be reduced in combination with altered seeding rates. Fertilization in complex grass - forb - shrub mixtures caused a decline in species diversity. Simple mixtures showed no effect. Mays and Bengtson (1978) found that tree seedlings may be outcompeted by excessive development of herbaceous cover when over-fertilization occurs. They recommended a combination of fertilization and herbicides where tree seedlings are desired.

Coarse-textured subsoils and glacial tills in subalpine areas frequently exhibit nitrogen deficiencies which result in persistent soil fertility problems (Berg and Barrau, 1978). Phosphorus is the other most frequently deficient soil nutrient on reclaimed areas (Schoenholtz and Burger, 1984).

Ziemkiewicz (1982) reported that a variety of Arctic, alpine, and subalpine reclamation studies have indicated that seeded species exhibited good initial growth, but declined in vigor as fertilization was withdrawn and dead plant material accumulated at the soil surface. He attributed increases in subalpine detritus to a combination of slow decomposition and increased shoot biomass from the previous year. Termination of a maintenance fertilization program will result in a gradual decline in detrital accumulation. Self-sustaining vegetative cover development will continue to be inhibited by poor nutrient cycling and scarcity of nitrogen-fixing species in subalpine areas.

Johnson (1980) recognized the importance of legumes in revegetation of disturbed lands. He stated that increasing nitrogen fertilizer costs coupled with the desirability of returning disturbed areas to a self-sustaining nutrient status as quickly as possible, provide good incentives to research biological nitrogen fixation.

Ziemkiewicz (1982) identified both immature and mature reclamation plant community development. He characterized the immature plant community phase as having a relatively small root system with little yearly decomposition, and with large proportions of available nutrients being moved from shoots to detritus. In subalpine areas, where rapid detrital decomposition does not generally occur, plant community nutrient deficiencies and productivity declines result. Nitrogen and phosphorus are immobilized more than other macronutrients. Ziemkiewicz (1982) postulated that high elevation areas are likely to require longer periods of maintenance fertilization. According to this author, mature plant communities exhibit larger root systems, larger yearly attrition, and rapid detrital decomposition. Nutrient cycling occurs rapidly and these communities do not require maintenance fertilization.

Legume growth on high altitude reclaimed areas is important for creating a self-perpetuating plant community with adequate nutrient cycling (Errington, 1978). Schoenholtz and Burger (1984) stated that as succession advances, dehydrogenase enzymatic activity levels increase. They found a positive correlation between enzyme activity levels and perennial grass or alfalfa productivity in introduced seed mixtures and between enzyme activity levels and perennial grass productivity in native seed mixtures.

Biondini et al. (1984) noted that although areas lacking fertilization tended to become forb-dominated, (as opposed to fertilized areas which became grass-dominated), they had to reject their hypothesis that fertilizer levels and soil thickness have a long-term effect on plant community species composition. Sadasivaiah and Weijer (1981) reported that applications of fertilizer to high altitude native grasses resulted in no significant growth increases. They attributed this observation to species adaptatations to low nutrient levels. The poor soil conditions in which these species (or ecotypes) originate make such adaptations a necessity for successful competition. An additional drawback of fertilizing at high altitudes is that the combination of fertilizer, drought and late season rainfall may create problems with the short summers by extending the growing season so much that native grasses do not have adequate time to become dormant.

Topsoil application ameliorates the requirements for fertilizers. McGinnies and Nicholas (1980) reported a linear increase in plant growth and productivity with topsoil depth. But, topsoil is often unavailable at high elevation sites (Brown et al., 1976). Fertilization may aid soil development and stabilization, particularly where topsoil is shallow (McGinnies and Nicholas, 1980).

Munshower and Neuman (1980) found lower macronutrient levels (nitrogen, phosphorus, potassium, magnesium and calcium) in plants growing on sites lacking topsoil compared to plants from topsoiled sites. The latter had macronutrient levels similar to native unmined soils. Ledgard (1974) noted that phosphorus applications increased pine and alder growth rates in the subalpine. But, the specific response by plants to fertilization treatments frequently depends on soil moisture regimes, other soil characteristics, the plant species in use and the distribution, frequencies and amounts of rainfall (Doerr and Redente, 1983). Potential usefulness of fertilization should be assessed on a site-specific basis.

Seeding

Successful seedling emergence, growth and establishment is affected by a variety of factors associated with seeding practices. Methods of seed application available on high elevation minesites are often limited because of rough, uneven terrain and steep slopes. Drill seeding may not be an option on many sites. The success of broadcast seeding varies with the species being seeded, moisture conditions at and subsequent to the time of seeding and techniques used (if any) to cover the seed following broadcasting (Cook et al., 1974).

After two growing seasons, native plant seeds which had been broadcast onto an unamended, rototilled surface produced a ground cover only 5 percent less than areas which had been fertilized and packed. Agronomic species might be expected to perform better if drill-seeded, but good success has been achieved on mountainous sites with the use of broadcast seeding (Wishart, 1984; Macyk, 1976).

Time of optimum seeding varies with species involved and site edaphic conditions. Where moisture is limiting, seeding should occur immediately prior to the time of optimum moisture conditions. While some authors favor fall seeding, others advocate spring seeding when legumes are contained in the seed mix (Vallentine, 1980; Macyk, 1976).

Slope

Post-mine landscapes in Canada commonly exhibit steeper topography than that which existed prior to mining (Berdusco and Milligan, 1977). A variety of reclamation problems can result from these changes (Lesko et al., 1975; McDonald and Errington, 1978; Veith et al., 1985).

Steep slopes can result in surface creep and accelerated erosion (Berdusco and Milligan, 1977). Lesko et al. (1975) found that increased slope gradients resulted in reduced establishment rates for seedlings, with the greatest declines occurring between 0 and 20 percent gradients. Further gradient increases resulted in lower rates of decline. Movement of soil particles down steep slopes hinders seedling establishment (Grossnickle and Reid, 1984; Errington, 1975). Erosion rates can be expected to double for each 10 percent increase in slope when the vegetative cover is below 50 percent (Rowell, 1981). Krause (1969) considered the maximum slope for successful revegetation to be 70 percent, while McDonald and Errington (1978) reported 62 percent as the steepest gradient conducive to vegetation establishment. Lesko and his co-workers described a 50 percent slope as being a more realistic upper limit for viable vegetative cover.

Steep slopes are frequently droughty in their upper portions as a result of limited snow accumulation and excessive runoff (Burns, 1980; Veith et al., 1975). Topographical control of snow distribution is a critical factor determining soil distribution and development in alpine areas. Formation of ridges that are barren in winter and dry in summer should be avoided (Johnson, 1980). Errington (1975) noted that declines in plant cover on steep logging road surfaces were probably related to a reduction in moisture. Conversely, large depressions with increased snow accumulation are undesirable because they have short, very wet growing seasons (Burns, 1980).

Aspect

Disturbance practices such as dumping procedures in mountainous terrain commonly increase slope uniformity and decrease microsite and aspect variations (Berdusco and Milligan, 1977). Filling of gullies and low areas often reduces drainage densities. Revegetation becomes more difficult as a result of these alterations, particularly if post-disturbance aspects are south or southwest facing. Southerly aspects have been found to be more difficult to reclaim because of temperature and moisture stress (Veith et al., 1985; McDonald and Errington, 1978).

In a study of logging road disturbances, Errington (1975) could find no relationship between aspect and total cover. He postulated that some species would be affected by variations in aspect.

The combination of slope and aspect affect soil temperature and moisture availability, which control seed germination and seedling emergence (Luke, 1981). Aspect also strongly influences wind exposure (Errington, 1975). Takyi (1980) noted that gusts of 100 to 120 km/h are frequent in exposed areas in the Rocky Mountains and Foothills of Alberta. The wind's dessicating effects may be largely responsible for the failure of an abandoned minesite in the Cadomin region to revegetate naturally after more than 26 years. High velocity gusts may result in damage to the seedbed and loss of seed. However, aspects facing upwind seed sources may also receive large quantities of native seed.

Microsite variability is a major determinant of whether plants will experience drought stress (Johnson, 1980). Lesko et al. (1975) reported that germination and seedling establishment occurred primarily in depressional microsites because of their more favorable environmental conditions. Rough-graded surfaces with 50 percent depressional microsites exhibited larger numbers of plants per unit area than bulldozer-packed surfaces. Seed placement tests indicated that germination patterns were not the result of seed accumulation in depressional areas. Increased plant densities were attributed to improved seedbed quality in microsites.

Water-holding capacities of depressional microsite soils were 3 to 7 percent higher than non-depressional area soils. This was attributed to higher runoff accumulation and lower evaporation rates in depressional microsites (Lesko et al., 1975). Depressional microsites are less susceptible to evaporation due to decreased wind exposure (Errington, 1975). Site preparation techniques can be used to create environmental conditions desired for seedling establishment (Grossnickle and Reid, 1984). Condensation traps and rock placement significantly improved microsite conditions for a number of shrub species at a site near Decker, Montana (Biggins et al., 1985). Hummocky surfaces have been successful in aiding plant establishment in Jasper National Park (Harrison, 1977).

In a study near Cadomin, Alberta, Takyi and Leitch (1981) noted that plants growing in troughs of a ridged treatment exhibited good growth and seed head production.

Troughs served as moisture collection and absorption areas. Spoil material in flowing water often collected in the troughs and buried the plants.

Seed Dispersal by Wind

Several authors have identified dispersal efficiency as a primary factor in native species invasion of disturbed sites (Gibson et al., 1985; Johnson and Van Cleve, 1976). Wind dispersal of seed is an important means of dispersal for many pioneer species (Errington, 1975).

The ability of undisturbed sites to provide adjacent disturbed areas with seed varies in terms of quality and quantity (Brady and Thirgood, 1982). Availability of seed from these undisturbed sites is a function of wind direction, seed source quality, quantities of available seed, duration of seed dispersal and dispersal distance (Zasada, 1971). These factors must be considered in order to assess revegetation potential of any site.

Presence of woody species can be a function of seed dispersal method and seed source proximity. Initial invasion is dominated by wind-disseminated species, while species disseminated by animals or those which spread by vegetative means appear more slowly (Humphries and Bradshaw, 1977).

Succession

Successional processes are considered important determining factors in establishment of self-perpetuating communities on reclaimed mined lands. These processes include interaction of biotic and physical environmental influences over time (Mackey and DePuit, 1985).

Several authors differentiate between primary and secondary succession (Revel et al., 1984). Primary succession occurs on sites where no plant growth has occurred previously. Areas of secondary succession are influenced by plant growth which has occurred in the past and modified environmental factors such as soil substrate. The process of secondary succession is frequently more rapid than primary succession because of the presence of plant propagules and soils more favorable to plant growth (Odum, 1971; Daubenmire, 1968).

The minesite under study is undergoing secondary succession because topsoil was replaced. Factors influencing the nature and rate of secondary succession on such sites include topsoil thickness, fertilization levels, seed mixtures and dispersal efficiency of colonizing species (Biondini et al., 1984; Gibson et al., 1985). Dispersal efficiency and establishment of colonizing species can be related to the nature of the seed source, methods of seed dispersal, proximity of the seed source to disturbed areas, soil physical and chemical properties, topography (including slope and aspect) and competition from previously established species.

Successional processes can be altered and/or enhanced by many reclamation activities. These include physical factors described earlier in this literature review, such as regrading to alter slope and aspect, and revegetation through seeding, planting and fertilization techniques. Individual species selected and their arrangement on the postmine landscape are considered critical to the successional process. Miller (1978) advocated the principle of nucleation, where seeded or planted 'patches' of vegetation serve as sources of nutrients and propagules to enhance further site colonization by native species. He noted that at the time of publication, the idea had not been tested on actual reclamation areas.

Native Versus Agronomic Species

Bell and Meidinger (1977) described an agronomic species as "a plant species selected and bred for specific agricultural purposes such as forage, hay or cover crops." A native species is a plant species occurring naturally within a region, and which is theoretically adapted to local climates and habitats (Bell and Meidinger, 1977).

Opinions regarding native and agronomic species use in minesite reclamation vary widely in the literature. Preferences include use of agronomic, native, or combination agronomic and native species mixtures.

Lesko et al. (1975) reported that agronomic species performance was at least equal to that of native species in the first two years following seeding. Redente et al. (1984) noted that agronomic grasses exhibited more rapid growth than native grasses. Tomm and Takyi (1981) found that most native grass species tested on high elevation sites were unable to develop plant cover rapidly enough to provide adequate erosion control. Agronomic species appeared to be superior for this purpose (Takyi, 1980).

Problems associated with use of native species include variable seed production, uneven ripening, low yields, seed shattering, hairs and awns, low seed viability and other seed harvesting and handling difficulties (Mitchell, 1972; Walker et al., 1977). These problems have contributed to insufficient commercial sources of high quality seed and resulted in limited large-scale use of native species in Canadian reclamation (Sadasivaiah and Weijer, 1980). Some problems may be solved through genetic manipulation or agricultural engineering technology, but seed produced by such processes is not yet commercially available.

Alteration of environmental conditions through mining may result in agronomic species being more suitable for revegetation purposes than native species (Johnson, 1980). Areas which have been fundamentally altered by mining activities may not remain suitable for native species present prior to disturbance (Selner, 1976). But, many agronomic species are unable to become established at higher elevations because of low air and soil temperatures, frost heaving damage, short growing season and high solar radiation levels (Klock et al., 1975).

A study in Colorado by Doerr and Redente (1983) indicated that agronomic species provided the greatest forb production. This observed difference between agronomic and native forb production was attributed to presence of alfalfa (Medicago sativa). Westar Mines, in the Crowsnest Pass region of British Columbia, has had good success with use of agronomic species in subalpine areas (Milligan and Berdusco, 1977; Ziemkiewicz, 1977). Agronomic species continued to reproduce and increase in cover and biomass at elevations up to 1700 m (Berdusco and Milligan, 1977).

High cost of native seed is a major consideration of mining companies when determining appropriate seed mixtures (Ziemkiewicz, 1977). Agronomic seed is easily available at low cost (Bell and Meidinger, 1977).

Even if agronomic species die out during or after the first growing season, they may have accomplished important reclamation goals (Johnson and Van Cleve, 1976). These cultivars may provide adequate short-term erosion control while simultaneously posing no threat of spreading. Agronomic species often render a site more favorable for native plant growth (Mitchell, 1972).

In a study of harsh subalpine minesites at Adanac and Cadomin, Alberta, Tomm and Russell (1980) found that the highest percent cover was achieved by a native seed mixture comprised primarily of wheatgrasses. Native mixtures containing no wheatgrasses exhibited very poor ground cover development. In contradiction with Takyi (1980), they suggested that effective erosion-controlling cover can be achieved on subalpine sites in Alberta through appropriate selection of native species. Native grass treatments exhibiting the best plant cover were comparable with cultivated mixtures.

Biondini et al. (1984) noted that agronomic species used for reclamation purposes have traditionally been selected for such characteristics as ease of establishment, high above-ground biomass production and strong positive responses to fertilization. Use of cultural practices such as fertilization could result in competitive exclusion of desirable native species and permanently affect succession.

Continued fertilizer applications often required by agronomic species increase reclamation costs (Walker et al., 1977).

Transplanting containerized native grass plants is described as an effective means of achieving rapid ground cover on drastically disturbed areas (Walker et al., 1977), but costs may be prohibitive. Russell (1979) noted that transplanted containerized plants produced limited cover for three years following transplantation. The technique may be useful for small critical areas, but is probably neither practical nor cost-effective on a large scale.

Native species will eventually invade stands of agronomic species unless the latter are continuously maintained (Mitchell, 1972). This is a positive attribute of agronomic species if the reclamation goal is site occupation by native species. Other positive attributes of native grasses include the ability to adapt to local soil and environmental conditions, a perennial nature and high forage quality (Sadasivaiah and Weijer, 1980). Adapted native species are particularly useful at high elevations because they survive with little maintenance (Wheeler and Sawyer, 1981; Willard, 1976; Vaartnou, 1976; Blake, 1981). Seeding native species can increase the rate of natural succession through the process of 'nucleation', where native species serve as 'nuclei' of propagule dispersal.

Native species have ecological, economic, and aesthetic advantages (Bell and Meidinger, 1977). Low maintenance expenses such as reduced needs for repeated fertilizing and reseeding may more than offset additional native seed costs (Ziemkiewicz, 1977).

Choice of suitable plant species for high altitude reclamation is important because poor decisions have resulted in past failures. A general bioengineering principle is to use only those species which have originated from sites with similar ecological conditions. Species choice is critical because successional processes in such areas are extremely slow (Schiechtl, 1980).

Research comparing use of native, agronomic, and combination native and agronomic seed mixtures has indicated that combination mixtures are superior (Doerr and Redente, 1983). Mixtures provide rapid establishment and production by means of agronomic species and increased long-term productivity and species diversity by means of native species (Brown et al., 1976; Johnson and Van Cleve, 1976). A well-planned seed mixture can result in vegetation cover that establishes rapidly, lasts for many years, provides good cover and is less vulnerable to pests, disease, drought and frost. Agronomic grass and combination native and agronomic grass - forb - shrub mixtures exhibited significantly greater above-ground production than pure native seed mixtures (Redente et al., 1984).

Both agronomic and native species are useful for site revegetation when adapted to disturbed areas. Species selection should be based on use of 'adapted' species, rather than native plants alone (Sindelar, 1982). The primary consideration should be suitability of plants to disturbed environments and the projected postmine land use (Johnson, 1980). Rapid growth of agronomic species may initially limit resource availability for native species through competitive interactions, but native species with superior adaptations will eventually outcompete agronomic species (United States Forest Service, 1979).

SITE DESCRIPTION

The study site involved in this research project is located in the Rocky Mountain Foothills 13 km north of the town of Grande Cache, Alberta. Areal extent of the site is approximately 91 hectares, with an upper elevation of nearly 1600 meters. The site is situated on the McEvoy anticline of Horse Mountain (Macyk and Steward, 1977).

Terrain in the area is characteristically steeply sloping. Soil mantles are generally thin and situated immediately above bedrock (Macyk and Steward, 1977). Prior to mining, soil cover within the mining area varied from 10 cm to 1 m, with a mean depth of 30 cm. Postmine coversoil depths vary from 5 to 35 cm in depth, with substantial portions of the site in the 10 to 25 cm coversoil depth range (Macyk, 1979).

The mined area climate is cold continental, characterized by brief, cool summers and long, cold winters. The mean annual temperature is approximately 2 degrees Celsius. Recorded frost-free periods have varied between 45 and 93 days, but frost can occur during any month of the year. Mean annual precipitation is between 50 and 65 cm (Macyk, 1977).

Well-drained upland sites typical of the mined area are dominated by lodgepole pine (Pinus contorta var. latifolia), with fewer numbers of white spruce (Picea glauca), Engelmann spruce (Picea engelmannii), black spruce (Picea mariana), subalpine fir (Abies lasiocarpa), quaking aspen (Populus tremuloides) and balsam poplar (Populus balsamifera) (Macyk, 1977).

Common shrubs include willow (Salix spp.), river alder (Alnus tenuifolia), Labrador tea (Ledum groenlandicum), tall bilberry (Vaccinium membranaceum), bearberry (Arctostaphylos uva-ursi), wild rose (Rosa woodsii), and twinflower (Linnaea borealis). Grasses and forbs include hairy wildrye (Leymus innovatus), spike trisetum (Trisetum spicatum), purple reedgrass (Calamagrostis purpurescens), bunchberry, (Cornus canadensis), fireweed (Epilobium angustifolium), Indian paintbrush (Castilleja miniata) and perennial lupine (Lupinus argenteus). Also present are Sphagnum spp., Dicranum spp. and Peltigera apthosa.

Agronomic species seeded on the site included smooth brome (Bromus inermis var. Carlton), creeping red fescue (Festuca rubra var. Boreal), timothy (Phleum pratense var. Climax), crested wheatgrass (Agropyron cristatum var. Fairway), Russian wildrye (Elymus junceus var. Sawki), alfalfa (Medicago sativa var. Rambler) and Alsike clover (Trifolium hybridum).

METHODS AND MATERIALS

Data Collection

Sampling point locations were predetermined by applying a 60 m interval grid pattern to a 1:3000 aerial photograph of the study site. The origin of the grid system was a randomly chosen point on the photograph. Application of the grid pattern to a map of the study site is depicted in Figure 2.

Each grid intersection falling on the study site represented an individual sampling point. Sampling points were sighted and measured. Known points on the aerial photograph were ground-truthed with on-site locations to improve accuracy. A central grid line of sampling points was staked initially. All other grid points were staked using the center grid line points for reference.

At each of the 220 sampling point locations, a 10 m tape was laid out due west from the stake. Daubenmire frames (Daubenmire, 1959) were placed at the 2, 4, 6, 8 and 10 m points along the north edge of the tape. The 20 cm sides of the frames were placed parallel to the tape, with the southeast corners located on meter marks.

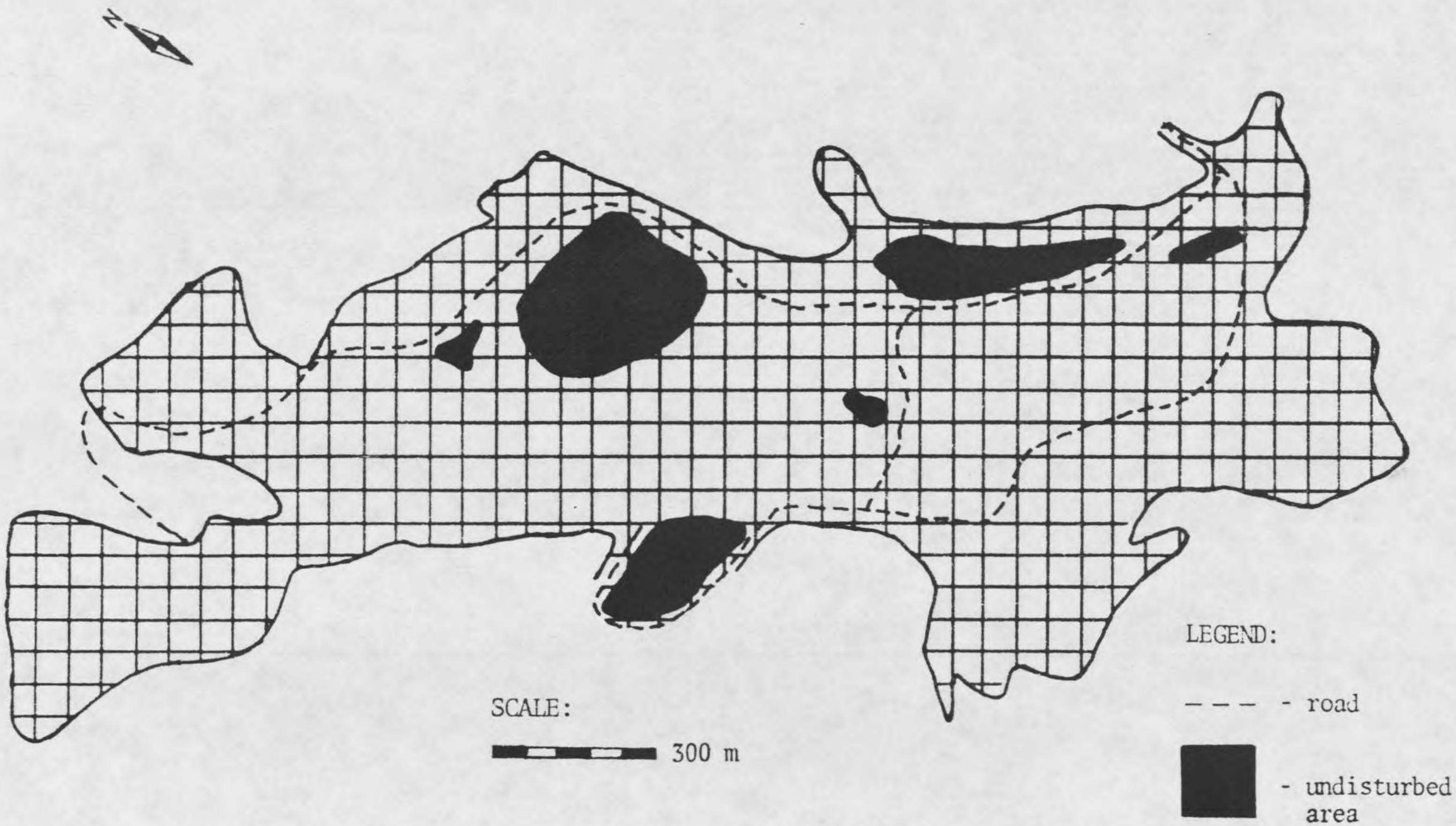

Figure 2. Grid application to a map of the study site.

Ocular estimates of percent cover (aerial) were recorded for species present within the frames. Native and agronomic species cover were grouped separately on data sheets. Species endemic to the area were considered native. Cultivars seeded on the area were considered agronomic. Although the terms as defined here are not mutually exclusive, no species present on the site fit both definitions. Unknown species were indicated as such on the data sheets and flagged for subsequent identification.

Additional data recorded for each site included percent slope, aspect in degrees, and estimates of limitations to plant growth caused by coarse fragments and coal waste as viewed at the ground surface. Estimates of limitations to plant growth caused by coarse fragments and coal waste consisted of ratings from 0 (no limitations) to 3 (severe limitations). A rating of 0 indicated a percent ground cover of coarse fragments of 1 percent or less, while ratings of 1, 2 and 3 indicated covers of coarse fragments of 2 to 5 percent, 6 to 20 percent and greater than 20 percent respectively.

These estimates differ from standard soil science methods for coarse fragment estimation. Coarse fragments are usually measured on a percent weight (Donahue et al., 1983) or volume basis (Ashby et al., 1982). Because of difficulty in distinguishing between coarse textured soil and coarse fragments less than 4 mm in diameter, coarse fragments between 2 and 4 mm in diameter were not included in cover estimations. Under-estimations of coarse fragment cover were anticipated.

Following completion of pre-selected point sampling, it was decided that sampling density had been inadequate for correct characterization of the native species invasion. Insufficient time remained to increase sampling density over the entire study site. As a result, additional sampling points were selected at mid-points between stakes in known areas of extensive native species invasion. Data collected from these points were retained in files separate from the 'base data set' which had reflected the original sampling scheme. Subjectively selected data points, hereafter referred to as the 'additional data set', were included only in final analyses to compare results from data files including these data to 'base data set' results. Conclusions from 'additional data set analyses' are included in this thesis for the sake of interest only, and are not intended to represent definitive conclusions of this research.

Means were taken of percent cover values along each mini-transect, with the means representing overall cover values for each grid point. This approach is valid because all other variables measured at the sampling points were