

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
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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.

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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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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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 pre-selected 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.

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).

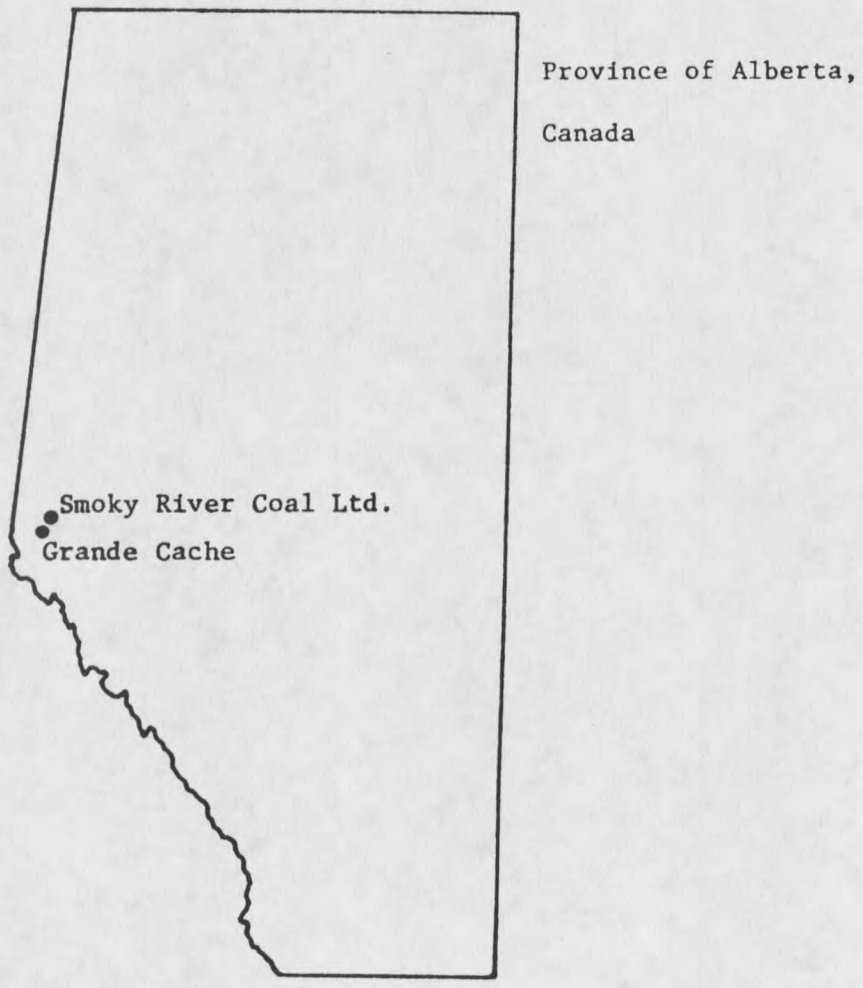


Figure 1. Location of Smoky River Coal Ltd..

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.

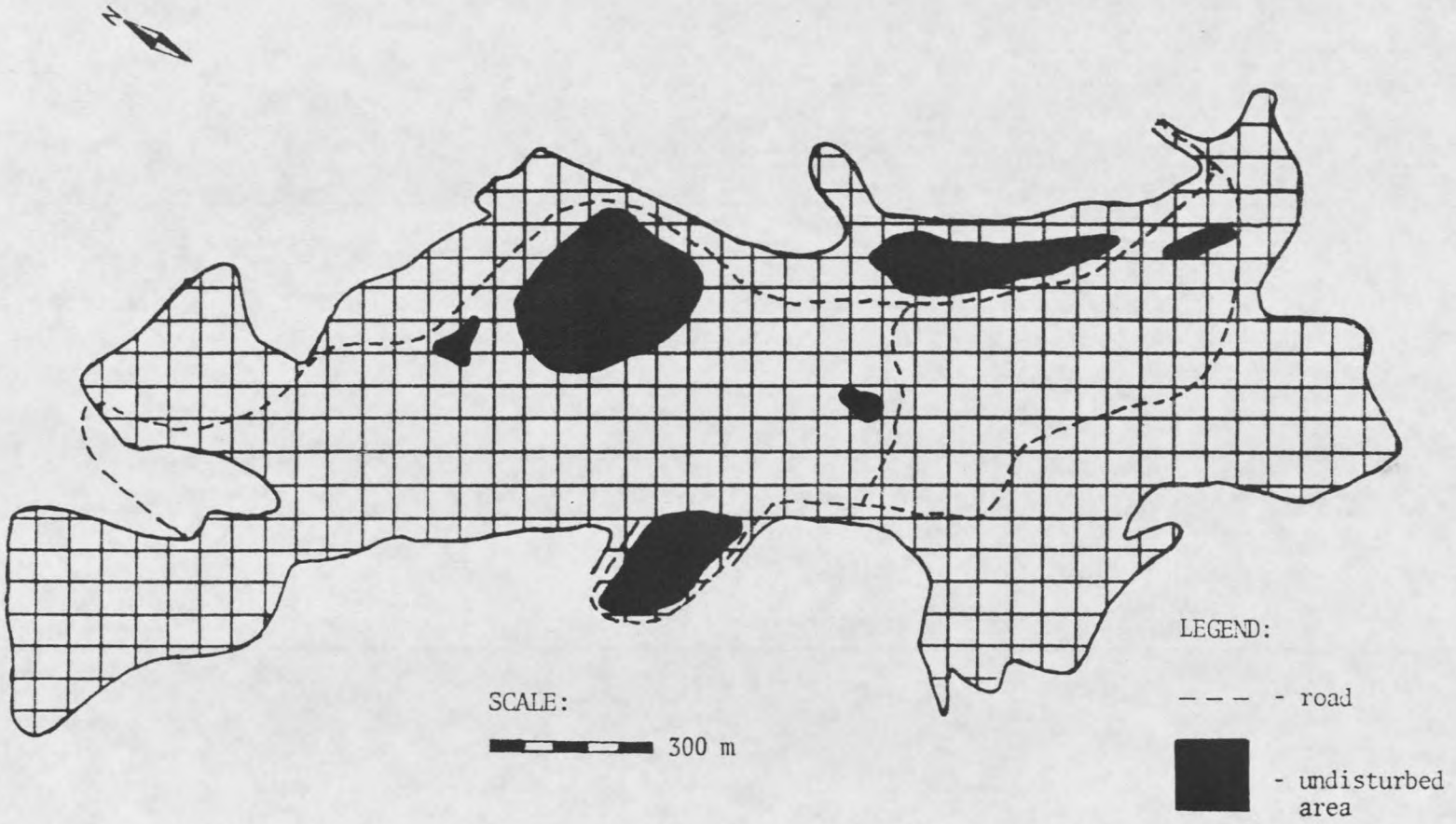


Figure 2. Grid application to a map of the study site.

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.

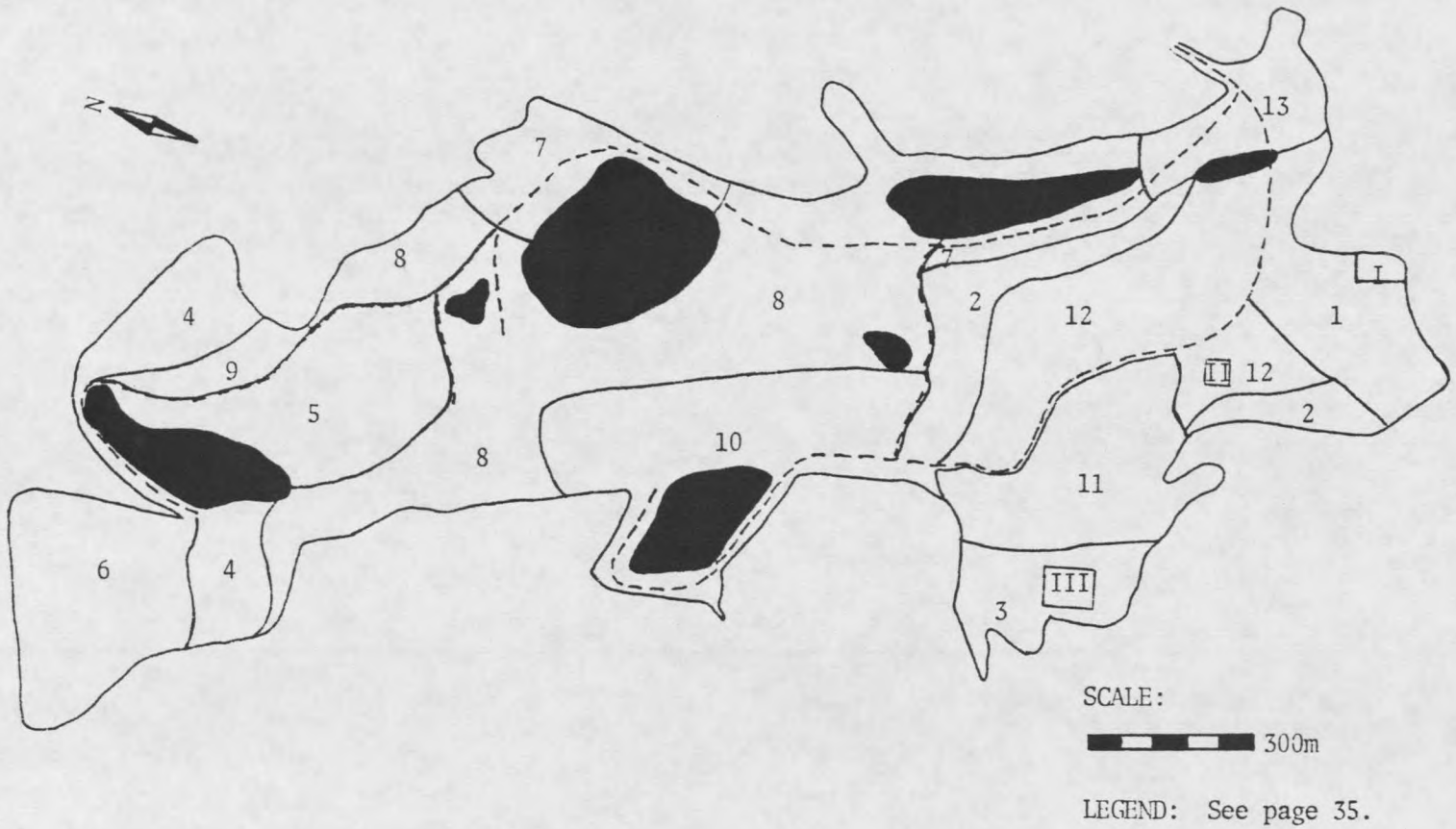
Means were taken of percent cover values along each mini-transect, with the means representing overall cover values for each grid point. This approach is valid because all other variables measured at the sampling points were

constant along each mini-transect and thus constant for individual sampling sites.

Plant specimens from the site were identified and collected. Dr. J.H. Rumely (Professor of Botany and Curator, Montana State University Herbarium) verified them.

Statistical Analyses

Data utilized in statistical analyses included that collected on the site and additional data available from previous site studies. Additional data included fertilization and seeding treatments, number of times fertilized, number of times seeded, topsoil depth, distance from the nearest undisturbed area and distance from the nearest westerly undisturbed area. Fertilization and seeding information was derived from a map completed by Alberta Research Council researchers to document seeding and fertilization activities on the site during the previous 14 years (Figure 3). Coversoil depth information for each sampling point was derived from a coversoil depth map documenting a postmine soil survey completed by Terry Macyk and other Alberta Research Council members (Figure 4). Distance from the nearest undisturbed area and distance from the nearest westerly undisturbed area were calculated from the 1:3000 aerial photograph overlaid with the sampling locations grid.



LEGEND: See page 35.

Figure 3. Seeding and fertilization information for Number 8 Mine.

Legend:

I — Experimental plot areas.

Forested (undisturbed).

1 — Seeded and fertilized Aug., 1973. Refertilized May, 1975, May 1978.

2 — Seeded and fertilized May, 1974. Refertilized May, 1975.

3 — Seeded and fertilized May, 1974. Refertilized May, 1975, May, 1977.

4 — Seeded and fertilized Aug., 1974. Refertilized May, 1975, May, 1977.

5 — Seeded and fertilized Aug., 1974. Reseeded and refertilized June, 1975.

6 — Seeded and fertilized, Aug., 1974. Reseeded and refertilized Aug., 1975, May, 1978.

7 — Seeded and fertilized June, 1975. Refertilized May, 1978.

8 — Seeded and fertilized Aug., 1975. Refertilized May, 1976.

9 — Seeded and fertilized Aug., 1974. Refertilized May, 1975, May, 1977, Aug., 1984.

10 — Seeded and fertilized Aug., 1975. Refertilized May, 1976, Aug., 1984.

11 — Seeded and fertilized May, 1974. Refertilized May, 1975, May, 1977, Aug., 1984.

12 — Seeded and fertilized, May, 1974. Refertilized May, 1975, Aug., 1984.

13 — Seeded and fertilized, June 1975. Refertilized May, 1978, Aug., 1984.

Figure 3 - continued. Seeding and fertilization information for Number 8 Mine.

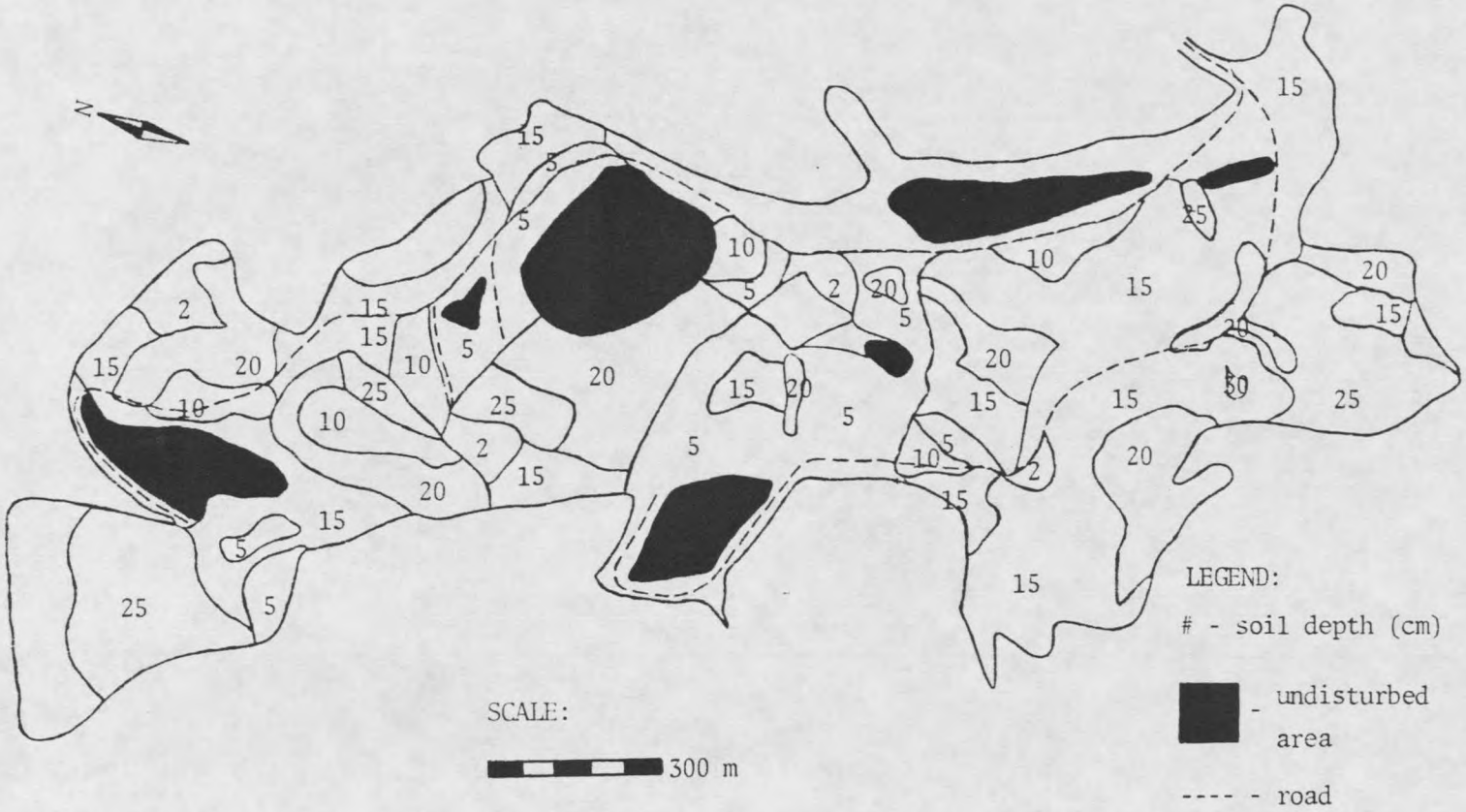


Figure 4. Soil depth map of the Number 8 Mine area.

Statistical analyses of data consisted primarily of covariance analyses. Dependent variables were cover values for native species. Independent variables analyzed statistically included percent slope, aspect, topsoil 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 the nearest westerly undisturbed area. Variables identified as class variables in covariance analysis procedures were coarse fragment rating and coal waste rating.

All statistical analyses were performed using the Version 5 SAS statistical package (SAS Institute, Cary, NC). Covariance analyses were completed through use of the GLM (General Linear Model) procedure.

Decisions regarding addition or deletion of variables to or from covariance analyses involved a combination of two criteria. The first of these was to examine printout P-values to determine whether a given variable was contributing significantly to the observed effect. Variables were considered significant when P-values were 0.20 or lower. Confidence levels of 80 percent or higher were accepted as significant. Secondly, F-tests were conducted to compare significance of variables in full versus reduced models.

Variable ranking was achieved by setting variables under comparison at unity at their means, and then comparing their values at one standard deviation unit higher than their means. Multiplication of each dependent variable's value for one standard deviation unit by its slope estimate resulted in a value which could be compared to numbers attained for other variables. The standard deviation unit effectively provided a common scale by which to compare variables measured by different methods.

RESULTS AND DISCUSSION

Dependent Variables

Table 1 contains a list of native species observed on the minesite. The dependent variable 'percent cover of native species excluding moss' refers to the total percent cover of any of the species listed in Table 1 excluding moss (*Dicranum* sp.). 'Native tree species' comprises all woody species observed on the minesite, including shrubs. The species included in this dependent variable were river alder (*Alnus tenuifolia*), Canada buffaloberry (*Shepherdia canadensis*), white-flowered Rhododendron (*Rhododendron albiflorum*), tall billberry (*Vaccinium membranaceum*), Engelmann spruce (*Picea engelmannii*), lodgepole pine (*Pinus contorta*), balsam poplar (*Populus balsamifera*), quaking aspen (*Populus tremuloides*) and willow (*Salix* spp.). 'Native nitrogen-fixing species' included river alder, bearberry (*Arctostaphylos uva-ursi*), and all Fabaceae species.

Table 1. Native species present on the Number 8 Mine.

FAMILY	SCIENTIFIC BINOMIAL
Asteraceae	Achillea millefolium L.
Asteraceae	Agoseris aurantiaca (Hook.) Greene
Asteraceae	Arnica cordifolia Hook.
Asteraceae	Aster conspicuous Lindl.
Asteraceae	Erigeron peregrinus (Pursh.) Greene
Asteraceae	Senecio triangularis Hook.
Asteraceae	Solidago spathulata DC.
Asteraceae	Taraxacum officinale Weber*
Betulaceae	Alnus tenuifolia Nutt.
Boraginaceae	Mertensia paniculata (Ait.) G. Don
Brassicaceae	Lepidium bourgeauanum Thell.
Campanulaceae	Campanula rotundifolia L.
Caprifoliaceae	Linnaea borealis L.
Caprifoliaceae	Sambucus racemosa L.
Cornaceae	Cornus canadensis (L.) Nutt.
Cyperaceae	Carex bebbii Olney
Elaeagnaceae	Shepherdia canadensis (L.) Nutt.
Equisetaceae	Equisetum arvense L.
Ericaceae	Arctostaphylos uva-ursi L. Spreng
Ericaceae	Rhododendron albiflorum Hook.
Ericaceae	Vaccinium membranaceum Dougl.
Fabaceae	Astragalus americanus (Hook.) M.E. Jones
Fabaceae	Astragalus robbinsii (Oakes) A. Gray
Fabaceae	Hedysarum alpinum L.
Fabaceae	Hedysarum boreale Nutt.
Fabaceae	Lupinus argenteus Pursh.
Fabaceae	Oxytropis sericea Nutt.
Fabaceae	Oxytropis splendens Dougl. ex Hook.*
Fabaceae	Vicia americana Muhl.
Fumariaceae	Corydalis aurea Willd.*
Gentianaceae	Gentianella amerella (L.) Borner
Juncaceae	Luzula piperi (Cov.) Jones
Liliaceae	Zigadenus elegans Pursh.
Onagraceae	Epilobium angustifolium L.
Orchidaceae	Habenaria hyperborea (L.) R. Br.
Pinaceae	Picea engelmannii Parry ex Engelm.*
Pinaceae	Pinus contorta Loudon var. latifolia Engelm.*
Poaceae	Calamagrostis purpurescens R. Br.
Poaceae	Critesion jubatum (L.) Nevski
Poaceae	Leymus innovatus (Beal) Pilger
Poaceae	Poa alpina L.*

Table 1. (continued).

FAMILY	SCIENTIFIC BINOMIAL
Pyrolaceae	Moneses uniflora (L.) A. Gray
Ranunculaceae	Anemone multifida Poir.
Ranunculaceae	Aquilegia flavescens S. Wats.
Rosaceae	Fragaria virginiana Duchesne
Rosaceae	Potentilla norvegica L.
Rosaceae	Rosa woodsii Lindl.
Rosaceae	Rubus idaeus L.
Rosaceae	Rubus pedatus J.E. Smith
Rubiaceae	Galium boreale L.
Salicaceae	Populus tremuloides Michx.
Salicaceae	Salix drummondiana Barr. ex Hook.*
Saxifragaceae	Parnassia palustris L.
Scrophulariaceae	Castilleja miniata Dougl. ex Hook.
Scrophulariaceae	Pedicularis bracteosa Benth.
Scrophulariaceae	Penstemon procerus Dougl. ex Grah.
Scrophulariaceae	Rhinanthus minor L.
	Dicranum sp.

*Not Verified

Specimens verified by Dr. J.H. Rumely, Prof. of Botany, Montana State University.

Variable Manipulation

Statistics for this study involved eleven series of covariance analyses. Each series of analyses included separate analyses with percent cover of moss, native species excluding and including moss, native tree species, native nitrogen-fixing species and native Asteraceae species as the dependent variables.

Ten variables were examined in the first series of covariance analyses. Significant results obtained in covariance analysis of nitrogen-fixing species were ignored

because of the relatively small number of observations compared to the large number of variables. Fertilization and seeding combination, distance from the nearest undisturbed area and soil depth were not significant. These variables were deleted from further analyses.

Results from the north versus south and east versus west codings of aspect indicated that a more appropriate analysis of aspect significance would involve comparison of northwest versus southeast aspects. The variable 'northwest versus southeast aspect' resulted from this change. It was also hypothesized that elevation or distance from the ridge summit on the mine site could be a factor in the native species reinvasion. The variable 'Distance C', representing distance from the southeast end of the minesite, was introduced to account for this trend. The southeast end of the minesite is the area of maximum elevation and the ridge summit on the minesite. Increasing distance from this area would reflect both increasing distance from the ridge summit and a decline in elevation. Because variables had been changed, deleted, and added in the transition between first and second series of covariance analyses, it was impossible to conduct F-tests to determine significance of deleted variables.

Following the second series of covariance analyses, it was hypothesized that number of times seeded and number of times fertilized could be contributing to the native species reinvasion. These variables were added for the third series of covariance analyses. P-values obtained in the third series of covariance analyses for 'Distance C', number of times seeded and number of times fertilized indicated that these variables were not significant contributers to the observed effect. Slope was significant only for percent moss cover. All four variables were deleted prior to further covariance analyses. F-tests examining the significance of the four deleted variables yielded no significant F-values.

P-values from the fourth series of covariance analyses indicated that the coal waste rating variable was not significant. It was deleted from subsequent analyses. F-tests indicated the variable had not been a significant factor in the model.

The fifth series of covariance analyses indicated that the variable representing percent cover of alfalfa was of significance only for moss and Asteraceae species. A sixth series of analyses was completed to determine significance of the variable's contribution. F-test calculations demonstrated that it had not contributed significantly.

No variable deletions were considered appropriate following the sixth series of covariance analyses. F-test summaries are presented in Appendix I.

Additional covariance analyses were completed to obtain more information. The seventh series of analyses involved a final 'recoding' of aspect to ensure that the northwest versus southeast recoding had been appropriate. Aspect was recoded to northeast versus southwest, and covariance analyses were completed both including and excluding northwest versus southeast codings.

Finally, a series of covariance analyses were completed which utilized the additional subjectively selected data points. The objective was to determine if research conclusions would be significantly altered by inclusion of the additional data.

Slope and P-value estimates for covariance analyses are listed by analysis series in Appendix II. Tables 5 through 20 contain slope and P-value estimates for analyses involving the base data set only. Tables 21 through 26 represent analyses which incorporated the additional data set. Original data is filed at the Alberta Research Council Terrain Sciences Department in Edmonton, Alberta.

Summarized covariance analysis results are presented by analysis series in Appendix III. Tables 27 through 74 include data for estimates involving the base data set only. Tables 75 through 92 represent analyses which included the additional data set. Appendix IV contains Least Significant Difference means separation test results for the sixth series of covariance analyses.

Coarse Fragments

'Coarse fragments at the soil surface' was a significant variable for most covariance analyses. It was significant for moss, native species and tree species (Appendix II, Table 16). Confidence levels were higher when the additional data points were considered (Appendix II, Table 21). The variable was significant at the 92 percent confidence level for Asteraceae species when the additional data points were included.

Although covariance analyses indicated that coarse fragment rating was an important contributor to the observed effect, interpretation of results is difficult. Given the nature of this variable, one might reasonably expect that there should be a clear linear relationship between percent cover and coarse fragment rating. Percent cover of native species should exhibit a positive or negative response to increased coarse fragment rating.

While the variable is significant, the relationship between percent cover and coarse fragment rating is neither clearly positive nor negative. The trend is one of initial decline between coarse fragment ratings of 0 and 1, followed by a gradual increase to a coarse fragment rating of 3 (Figures 5 through 10).

Examination of results from the Least Significant Difference (LSD) means separation tests complicates interpretation of the results. LSD tests for coarse fragment ratings with percent cover of moss as the dependent variable (Appendix IV, Table 93) indicate that a coarse fragment rating of 1 is significantly different from coarse fragment ratings of 2 or 3, but not from a rating of 0. A rating of 0 is not significantly different from any other rating, and ratings of 2 and 3 are not significantly different from each other.

LSD tests for coarse fragment ratings with percent cover of native species excluding moss as the dependent variable (Appendix IV, Table 94) indicate that a coarse fragment rating of 0 is significantly different from ratings of 1 and 3, but not from a rating of 2. There are no other significant differences for this set of analyses.

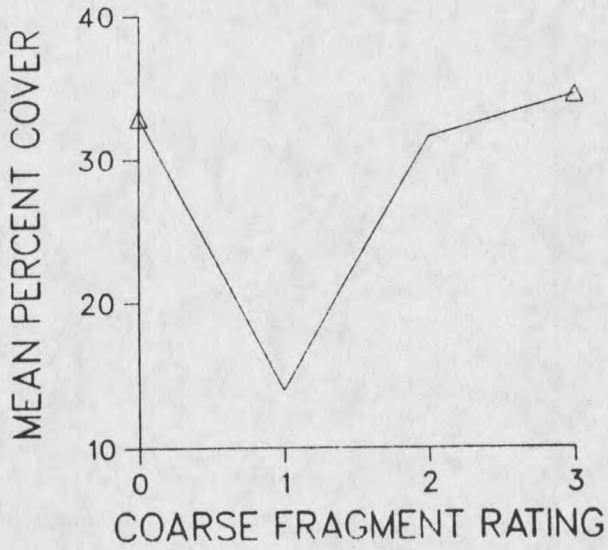


Figure 5. Percent moss cover with increasing coarse fragment rating.

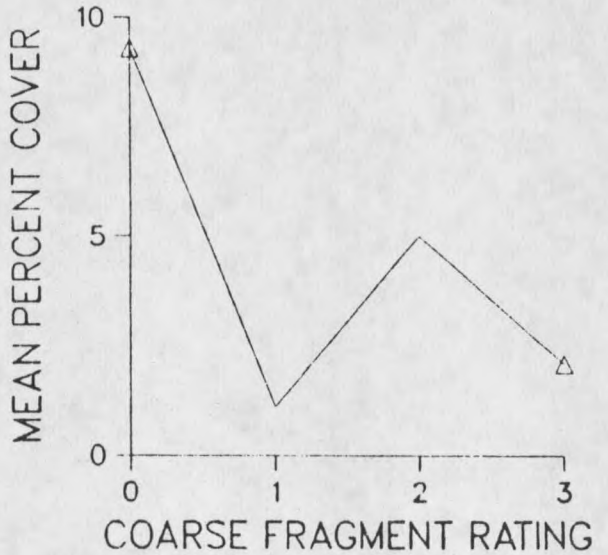


Figure 6. Percent native species cover with increasing coarse fragment rating (excluding moss).

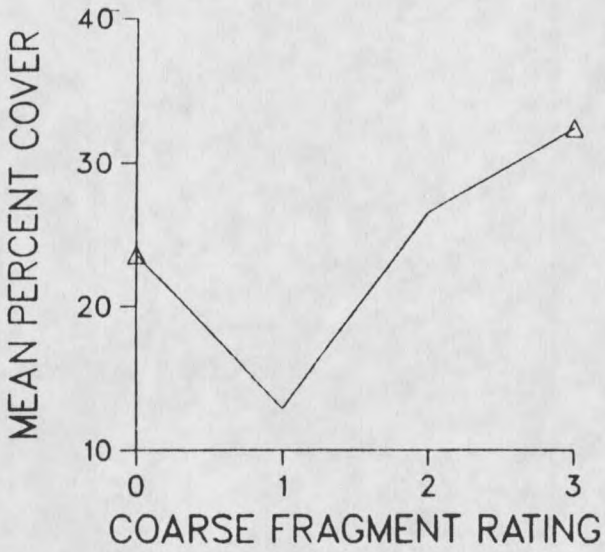


Figure 7. Percent native species cover with increasing coarse fragment rating (including moss).

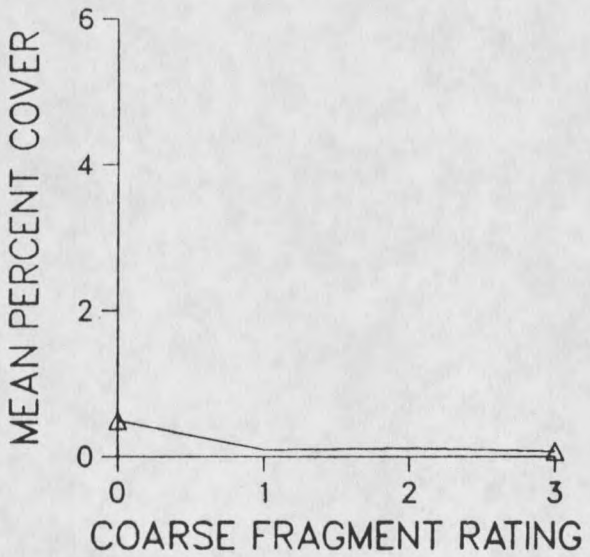


Figure 8. Percent native tree species cover with increasing coarse fragment rating.

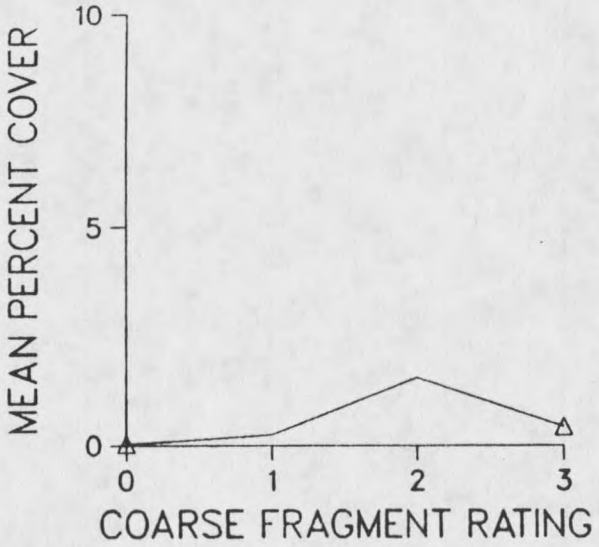


Figure 9. Percent native nitrogen-fixing species cover with increasing coarse fragment rating.

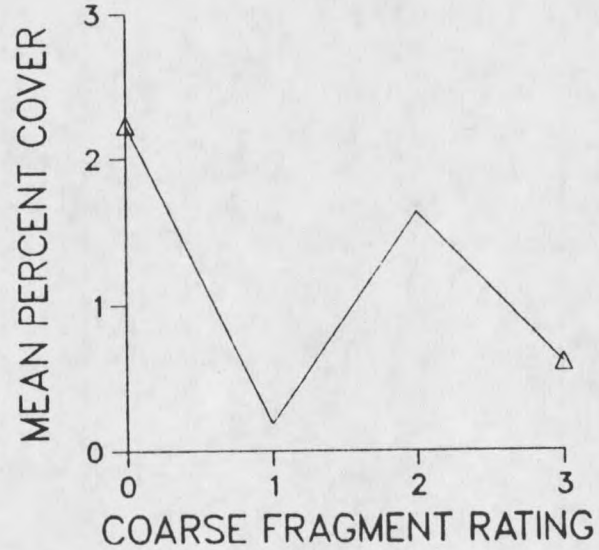


Figure 10. Percent native Asteraceae species percent cover with increasing coarse fragment rating.

Analysis of LSD test results for coarse fragment ratings with native species including moss as the dependent variable (Appendix IV, Table 95) yields slightly more significant differences. A coarse fragment rating of 1 is significantly different from all other coarse fragment ratings. There are no other significant differences according to this test. As indicated by Tables 96 through 98 in Appendix IV, results of LSD tests for the other dependent variables are similar to those just described.

There are few significant differences between coarse fragment ratings in terms of percent plant cover according to the LSD means separation test. It is one of the most powerful tests for detecting significant differences between means. The test compares pairs of means using a comparison-wise error rate and a constant least significant difference, so that the probability of Type I errors (false significances) is increased (Chew, 1976).

Trends depicted in Figures 5 through 10 have little importance. LSD test results suggest that there is no correlation between coarse fragment rating and dependent variable cover. This contradicts covariance analysis results. There may be a problem of factor interaction between coarse fragment ratings and other site variables. Another problem is the low number of native species observations at coarse fragment ratings of 0 and 1.

Although it is clear that coarse fragments significantly affect percent cover of native species, it is impossible to satisfactorily explain that relationship based on these results and analyses. But, there is a positive linear relationship between coarse fragment rating and number of native species observations. Number of native species observations increases with coarse fragment rating (Figures 11 through 22).

Competition from seeded agronomic species probably contributed to this relationship. Competition is probably greatest on sites most favorable to growth of these species. Such sites include those with deeper coversoil and better moisture and fertility relations. Thinner coversoil mantles on sites of higher coarse fragment ratings are expected to contribute to decreased competition from seeded agronomic species, with resultant improved viability opportunities for encroaching native species.

Secondly, coarse fragments may be important in creating favorable microsites for native species. Coarse fragments create a variable ground surface with depressional areas of moisture and soil collection, temperature gradations caused by shading and protection from wind. The resultant mosaic of environmental conditions can inadvertently create conditions conducive to native species establishment and growth.

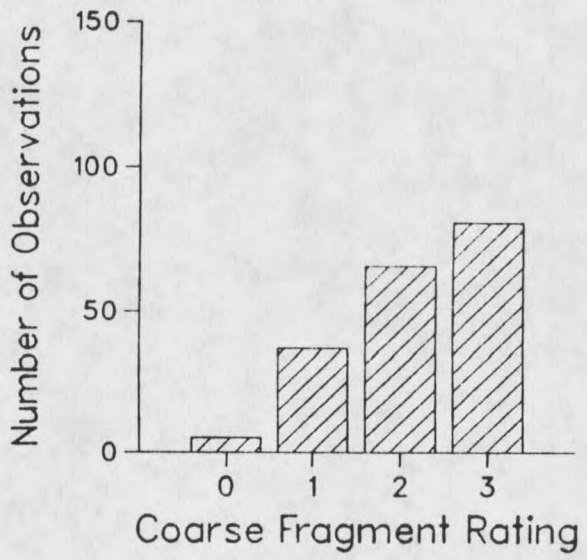


Figure 11. Number of moss percent cover observations with increasing coarse fragment rating.

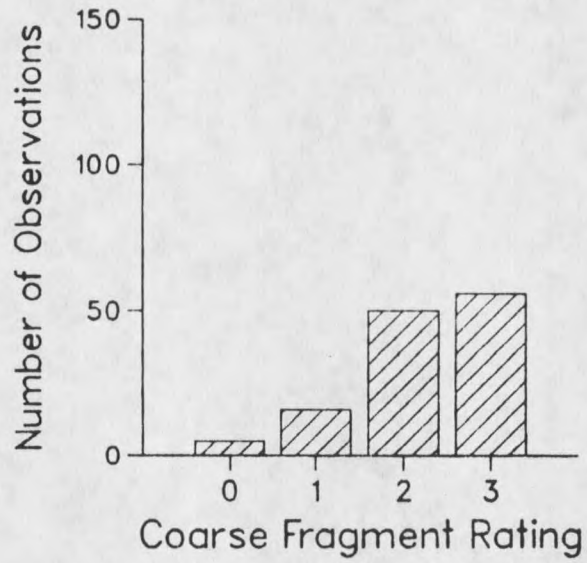


Figure 12. Number of native species percent cover observations with increasing coarse fragment rating (excluding moss).

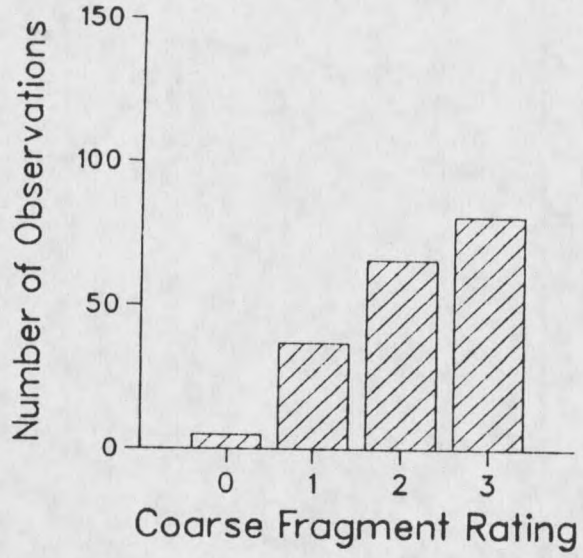


Figure 13. Number of native species percent cover observations with increasing coarse fragment rating (including moss).

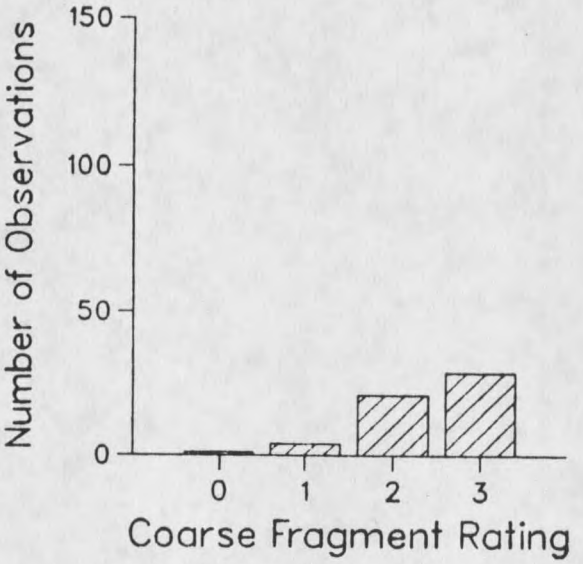


Figure 14. Number of native tree species percent cover observations with increasing coarse fragment rating.

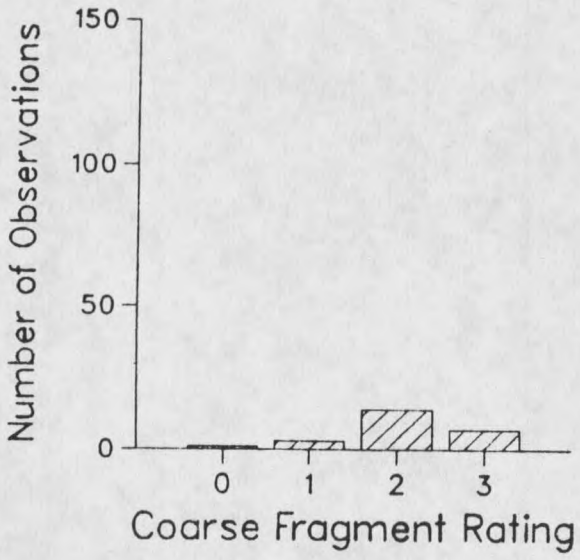


Figure 15. Number of native nitrogen-fixing species percent cover observations with increasing coarse fragment rating.

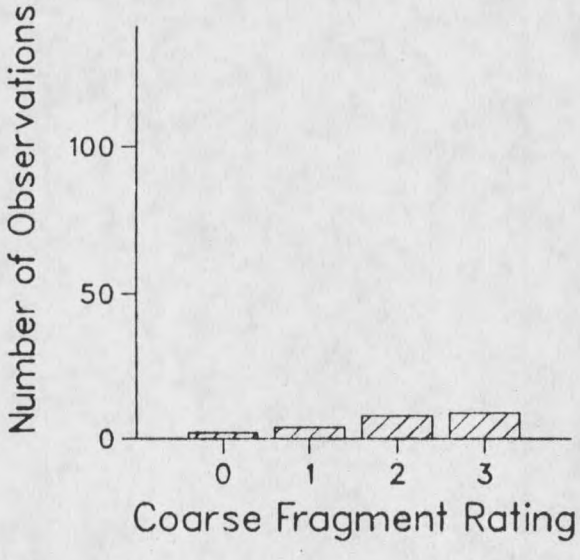


Figure 16. Number of native Asteraceae species percent cover observations with increasing coarse fragment rating.

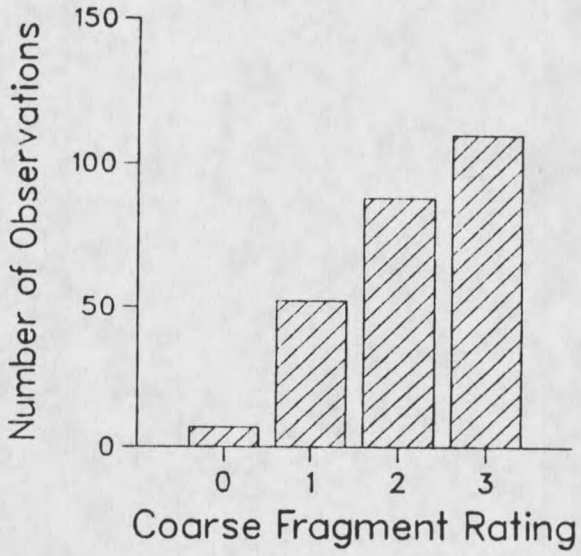


Figure 17. Number of moss percent cover observations with increasing coarse fragment rating (additional data set).

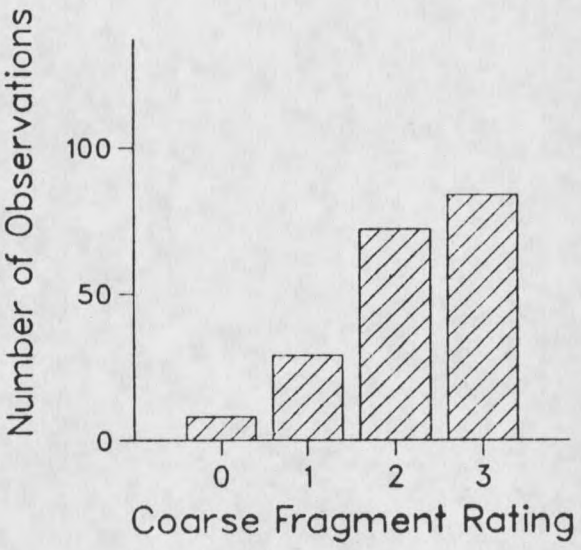


Figure 18. Number of native species percent cover observations with increasing coarse fragment rating (excluding moss) (additional data set).

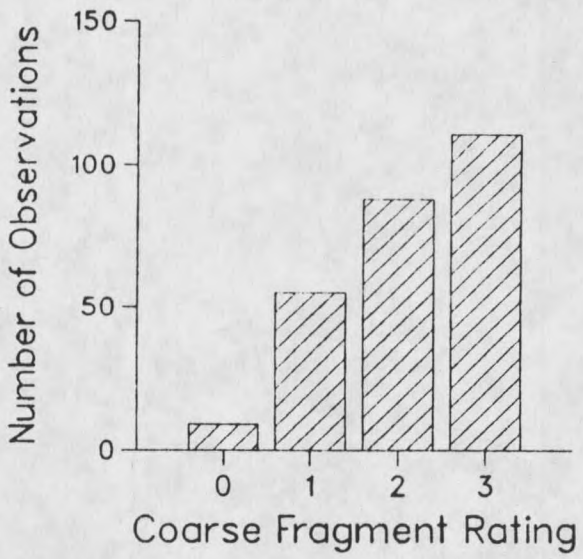


Figure 19. Number of native species percent cover observations with increasing coarse fragment rating (including moss) (additional data set).

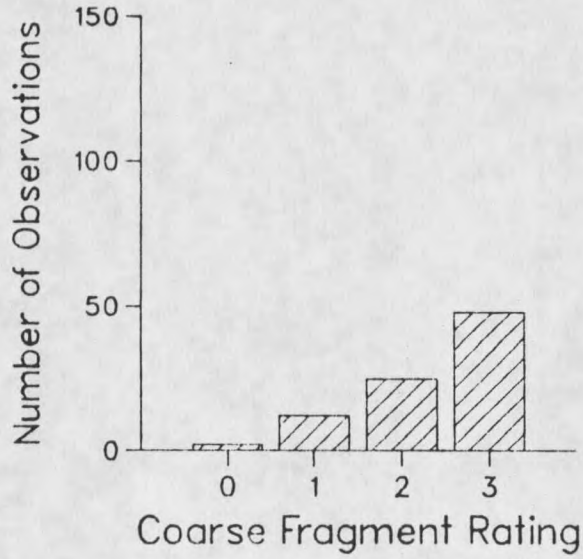


Figure 20. Number of native tree species percent cover observations with increasing coarse fragment rating (additional data set).

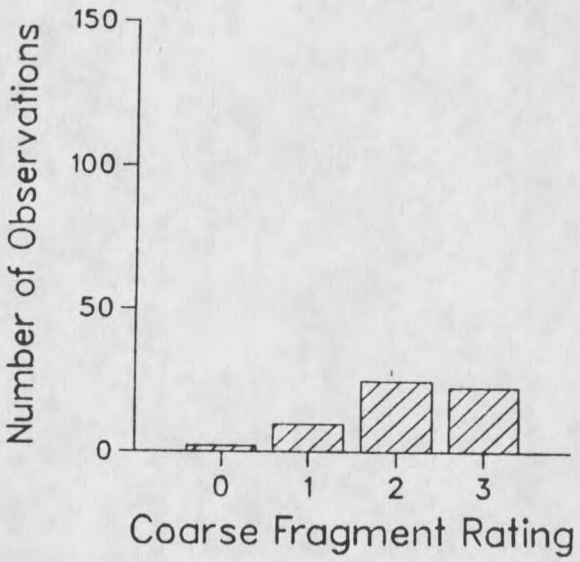


Figure 21. Number of native nitrogen-fixing species percent cover observations with increasing coarse fragment rating (additional data set).

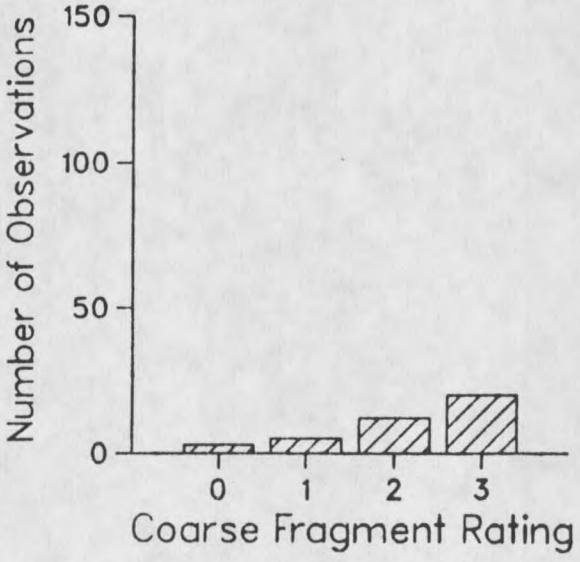


Figure 22. Number of native Asteraceae species percent cover observations with increasing coarse fragment rating (additional data set).

Many sites high in coarse fragments were located on steep slopes with little coversoil. While lack of soil on these areas reduces the amount of moisture available for plant growth, adverse effects are ameliorated by coarse fragments present at the ground surface. Coarse fragments increase surface roughness and dissipate erosive energy of runoff water. Depressions created by coarse fragments can trap moisture and channel it into areas of infiltration.

Texture of Number 8 Mine coversoil was a fairly uniform silty clay loam throughout the site (Macyk, 1977). But, bulk density varied as a result of organic matter accumulation caused by site vegetation and compaction which had occurred during site preparation. The beating action of rain onto bare mined areas would have also increased soil compaction (Macyk, 1977). Minimum compaction probably occurred on high relief areas, which were also areas of maximum ground surface coarse fragment cover.

Coversoil Depth

Coversoil depth was not identified as a significant factor contributing to observed cover (Appendix II, Table 6). Failure to achieve a significant linear relationship may partially result from absence of control areas lacking coversoil. Still, there was a good representation of different coversoil depths on the site (Figure 4).

The implication is that coversoil depths of 5 to 35 cm have no effect on native species cover. It should not be concluded that coversoil has no beneficial effect on native species growth. Any amount of coversoil may benefit native species growth, but differences in effects of various coversoil depths might not be easily detected when the minimum required amount has been supplied. The effect could be similar to that of a threshold value, where there are marked differences below the threshold value, but where further increases in the resource beyond the threshold level fail to yield similar response changes.

Another possibility is that percent cover is not a sensitive or appropriate indicator of plant response to variations in coversoil depth. When native species encroachment has increased substantially beyond what currently exists, it is possible that cover of various native species may adequately reflect variations in coversoil depth. An observational study of this type is not the best way to approach examination of this variable, particularly at this early stage in successional development of the reclaimed area.

Fertilization

Coding of fertilization and seeding treatments into 13 fertilization and seeding treatment combinations failed to

result in any significant correlation between native species cover and treatment combinations. Conversion of the 'seeding and fertilization treatment combination' variable to 'number of times fertilized' and 'number of times seeded' yielded similar results. There was no significant relationship between cover of native species and number of times the area had been seeded of fertilized. Although this may be a real effect, it is likely that lack of control areas was a major contributer to absence of an observed effect. No portions of the study area had been fertilized 0 or 1 times. There were no unseeded areas.

Significant differences in species composition and percent cover would have probably occurred on unfertilized and/or unseeded areas. Analysis of areas fertilized 2, 3 or 4 times and seeded 2 or 3 times is unlikely to have yielded as great a difference between fertilization and seeding repetitions as between untreated and treated areas. Without data from untreated areas, it is impossible to arrive at a definite conclusion regarding fertilization and seeding effects on the native species invasion.

Slope

Effects of slope on native species growth are significant for moss. Tables 9 and 10 in Appendix II are the most accurate representation of this variable because

they contain the lowest number of variables for covariance analyses in which slope was considered. Analyses indicate a positive relationship between moss percent cover and slope (Appendix II, Tables 5, 7 and 9). Initially, this is contrary to what one expects. Steeper slopes on minesites tend to be erodible, have less coversoil and are generally less stable. They should not be conducive to plant growth. Yet, their lack of coversoil and increased coarse fragments near the soil surface could make them more conducive to moss growth. Aside from decreased competition from other species, benefits of such sites could include favorable microsites for moss establishment.

It is important that slope was not a significant variable influencing cover of species other than moss (Appendix II, Tables 6, 8 and 10). Despite the variety of slopes, analyses do not indicate native species preferred level areas to steep slopes or vice versa. It is possible that an insufficient variety of slopes and/or data points were sampled for an accurate representation of slope effects. But, the large sample size and variety of slopes sampled would tend to preclude this possibility. Slope alone is probably not a significant determinant of native species invasion on this site. Slope may interact with other variables such as aspect. Slope shape may have been more important that slope angle.

Aspect

Aspect was originally recorded in degrees, and subsequently coded to north versus south and east versus west. Analyses indicate a strong positive correlation between percent cover of moss and northerly aspect (Appendix II, Tables 5 and 6). Increased moisture supply on northerly aspects as compared to southerly aspects is probably a major contributing factor.

Of additional interest is the strong negative relationship between percent cover of seeded agronomic species and westerly aspect. Success of agronomic species on this site has been greatest on easterly aspects. Moisture relations are likely to be a dominant factor influencing this relationship. Easterly slopes on this study site receive less wind and intense sunlight, thus contributing to a more mesic environment on these aspects.

Recoding of aspect to northwest versus southeast aspects resulted in significant values on subsequent covariance analyses (Appendix II, Tables 7 through 20). There is a positive relationship between moss cover and northwest aspects (Appendix II, Table 15). Native species excluding moss show a similar trend, with cover significantly higher on northwest than southeast aspects.

Consideration of native tree species, legumes, and Asteraceae species on a separate basis failed to yield significant aspect results. Other native species must be contributing to the observed effect.

Nitrogen-fixing species and Asteraceae species are significantly affected by changes from northeast to southwest aspects (Appendix II, Table 18). Data indicate that nitrogen-fixing species cover is higher on northeast aspects. Asteraceae species favor southwest aspects. Native species (excluding moss) show a positive relationship between southwest aspect and cover.

Moss favors northwest aspects only. Native species excluding moss exhibit greater cover on west aspects, with northwest aspects having the strongest positive effect. Nitrogen-fixing species are the only native species group to favor east aspects. Northeast aspects are preferred.

Trends observed here are probably related to aspect effects on seed and moisture availability. Predominance of winds from the southwest in this area is likely to make slopes with west aspects more conducive to receiving wind disseminated spores and seeds. Simultaneously, the force and frequency of these winds is likely to create conditions too dry, cold, or otherwise unfavorable to seedling establishment and growth on southwest aspects. Northwest aspects could receive a significant proportion of the wind

disseminated spores and seeds while being sufficiently protected from the drying forces of wind and sunlight to provide favorable growing conditions for native species.

Northeast aspects are cooler and more mesic than any other aspect. Although wind-disseminated seeds would have reached these aspects less frequently in this area, nitrogen-fixing species were found to favor this aspect. Moisture conditions on northeast aspects are probably the primary reason for nitrogen-fixing species existence there.

Addition of the extra subjectively selected data points to the covariance analysis resulted in few changes to native species trend results (Appendix II, Table 22). Tree species preferred northwest aspects. The confidence level for nitrogen-fixing species preference of northeast aspects increased from 89 to 94 percent.

Distance From The Nearest Undisturbed Area

'Distance from the nearest undisturbed area' (Distance A) was not significant for any of the native species variables (Appendix II, Table 6). Site-specific characteristics may have been major contributer to the lack of significance. Distance from the nearest undisturbed area should not be disregarded as a possible factor in native species invasions on other sites.

Site-specific characteristics confounding this variable could include slope trends, site shape and prevailing wind direction. The minesite itself was elongated in a generally north-south direction, while prevailing winds were from the southwest. The force and constancy of the wind probably significantly reduced contribution of wind disseminated seed and spores from the site's eastern edge. Much of the site also sloped down to the east. Potential wind-disseminated seed on eastern edges of the minesite had to disperse against prevailing winds and a slope gradient.

Distance From The Nearest Westerly Undisturbed Area

'Distance from the nearest westerly undisturbed area' was significant for nearly all covariance analyses (Appendix II, Tables 5 through 26). There is a negative correlation between distance from the nearest westerly seed source and percent cover of native species excluding moss. The effect is strongest for tree species.

Most native species observed on this site rely heavily on wind for seed dissemination. Prevailing winds from the west disseminate seed away from the westerly edges of the minesite. As distance from westerly edges increases, the number of seeds carried by the wind decreases, with a corresponding reduction in native species cover.

Percent Cover of Alfalfa

Percent cover of alfalfa has a significant negative effect on the percent moss and Asteraceae species cover (Appendix II, Tables 13 and 14). This negative relationship could be a result of shading by alfalfa. Other native species may be more shade tolerant. Also, increased available nitrogen in the vicinity of alfalfa plants may enhance agronomic species, which then outcompete moss and Asteraceae species.

Variable Ranking

Figure 23 ranks the relative significance of independent variables included in covariance analyses of moss percent cover. Coarse fragment rating is the most significant contributer to the observed effect, followed closely by the variable for northwest versus southeast aspect. Percent cover of alfalfa is an intermediate contributer to analysis results, with percent slope acting as the least significant contributer.

The three highest ranked variables account for an R-square value of approximately 0.15, with the value expected increase slightly when percent slope is included (Appendix III, Table 54). While the four variables are significant variables, they explain only approximately 15 percent of the factors affecting moss percent cover on the minesite.

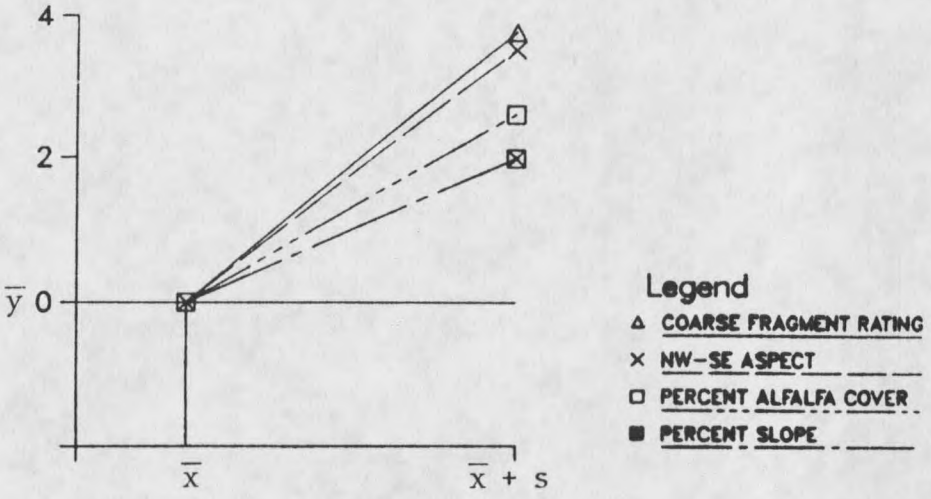


Figure 23. Ranking of variables significant in covariance analyses of moss percent cover.

Figure 24 ranks variables significant in analyses of native species excluding moss. Although coarse fragment rating again contributes most to analysis results, distance from the nearest westerly seed source (Distance B) ranks second, followed by northwest versus southeast aspect and northeast versus southwest aspect. The R-square value for these variables is 21 percent (Appendix III, Table 61).

Variables significant in analyses of native species including moss are identical to those identified for moss analyses (Figure 25). Moss constituted the majority of native species cover observations and biases results of native species analyses which include it. Coarse fragment rating is superceded by northwest versus southeast aspect.

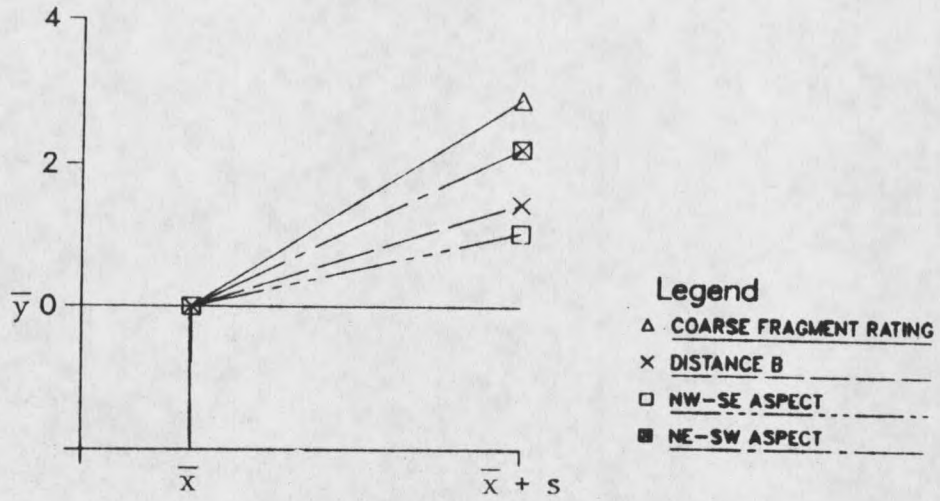


Figure 24. Ranking of variables significant in covariance analyses of native species percent cover (excluding moss).

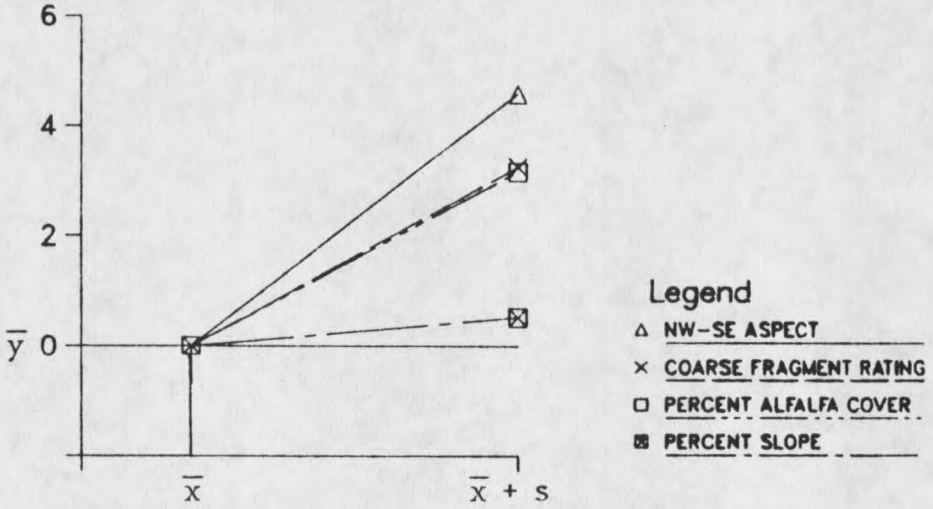


Figure 25. Ranking of variables significant in covariance analyses of native species percent cover (including moss).

A ranking for variables contributing to covariance analyses of native tree species is presented in Figure 26. Coarse fragment rating is ranked as most important, followed by distance from the nearest westerly seed source. The R-square value was approximately 26 percent (Appendix III, Table 56).

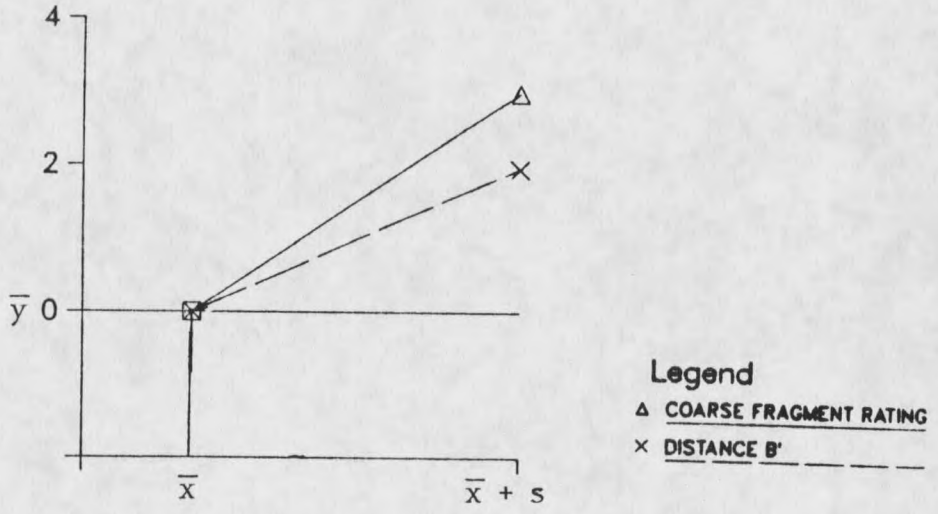


Figure 26. Ranking of variables significant in covariance analyses of native tree species percent cover.

Northeast versus southwest aspect was the only variable significant for covariance analyses of nitrogen-fixing native species (Appendix II, Table 18). These species preferred northeast to northwest aspects.

Figure 27 ranks variables significant for Asteraceae species covariance analyses (Appendix II, Tables 14 and 18). Alfalfa cover is most important, followed by distance from the nearest westerly undisturbed area and northeast versus southwest aspect. The R-square is 32 percent (Appendix III, Table 68).

Figures 28 through 30 represent analyses comparable to those for Figures 23 through 25 respectively, with the exception that the additional data points are included.

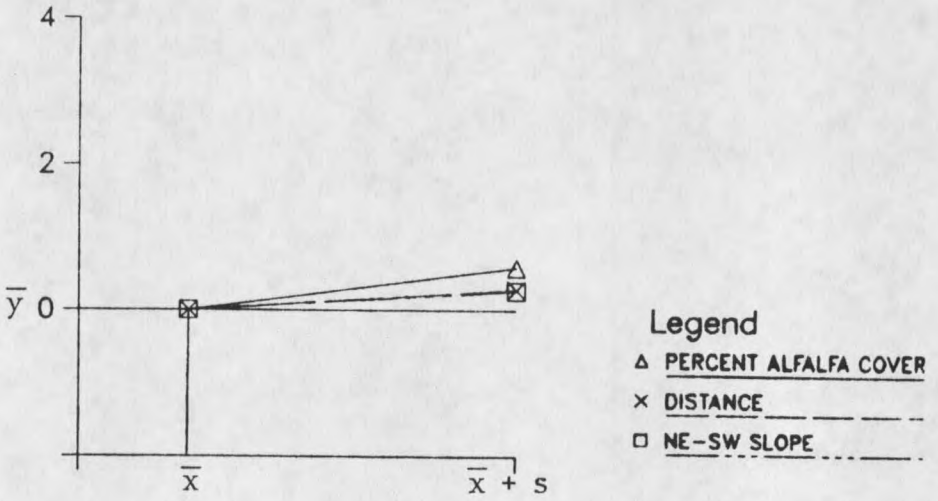


Figure 27. Ranking of variables significant in covariance analyses of Asteraceae species percent cover.

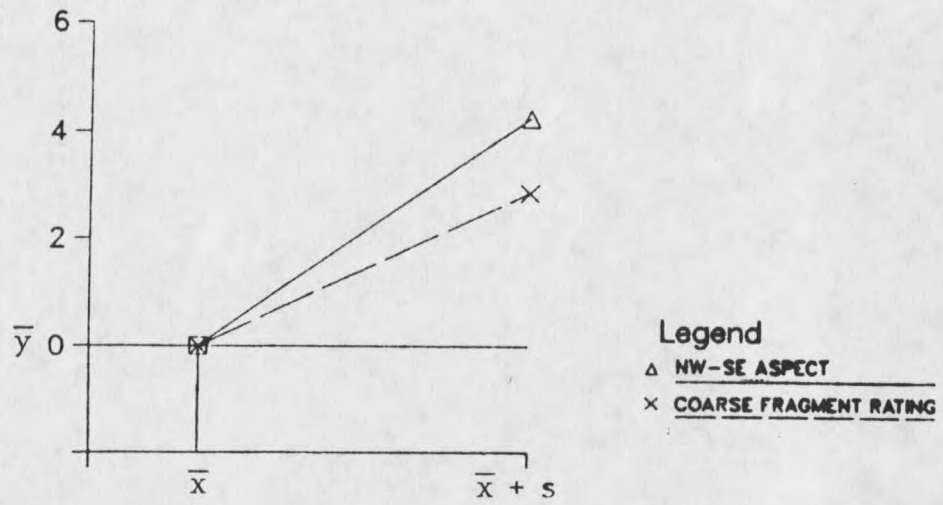


Figure 28. Ranking of variables significant in covariance analyses of moss percent cover (additional data set).

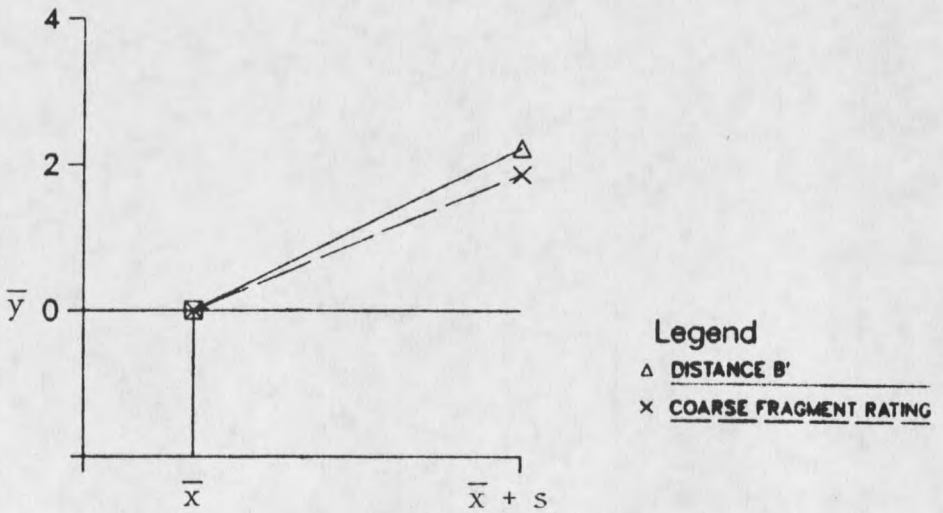


Figure 29. Ranking of variables significant in covariance analyses of native species percent cover (excluding moss) (additional data set).

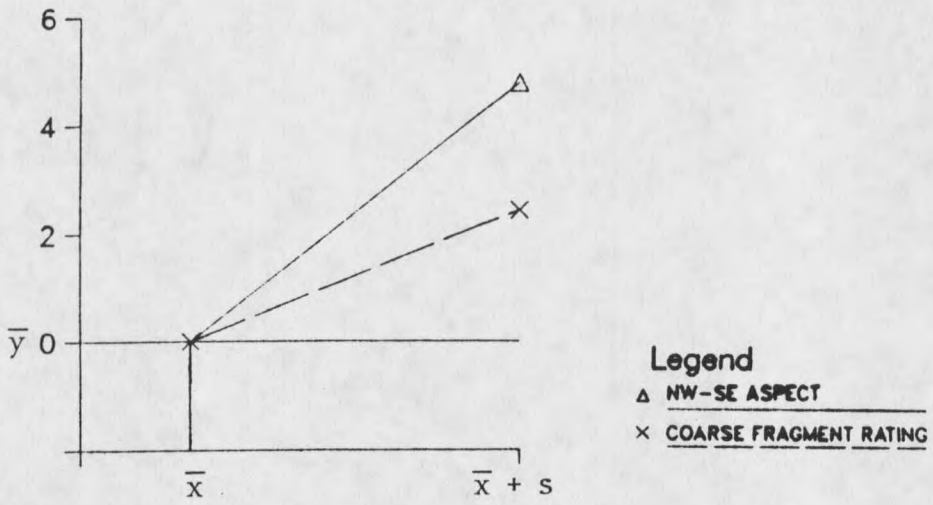


Figure 30. Ranking of variables significant in covariance analyses of native species percent cover (including moss) (additional data set).

While most variables included in these rankings are significant at the 90 percent confidence level, they account for R-square values of approximately 0.2. Variables are significant contributers to the observed effect (i.e. native species cover), but they account for only approximately 20 percent of native species cover values when a linear relationship is modelled.

If alteration of mining and reclamation plans to manipulate these variables for enhancement of native species invasion resulted in even a 10 percent increase in native species coverage, effects could be dramatic.

Such an increase in onsite native species coverage would greatly improve the potential for further spread of native species seed on the site.

There is also a possibility that covariance analyses have correctly identified the independent variables of greatest importance to the native species invasion, but that a model other than a simple linear one could have improved the R-square values substantially.

In terms of variable importance, it is evident that coarse fragment rating is the most important contributing variable. Northwest versus southeast aspect ranks second for moss analyses, but is replaced in importance by distance from the nearest westerly undisturbed area for most other native species analyses. Percent cover of alfalfa ranks third overall for moss analyses, but is replaced by either one of the two aspect variables for most other analyses. Of the variables ranked in these analyses percent slope appears to be least important.

SUMMARY AND CONCLUSIONS

Presence of native species on reclaimed high elevation minesites in Alberta is valuable for provision of long term self-sustaining erosion control and nutrient cycling with few maintenance requirements. But, seed supplies of species adapted to such sites are usually difficult and expensive to obtain. Commercial supplies of grass species adapted to these areas are only now being developed, and were not available in the mid-1970's when Smoky River Coal Ltd.'s Number 8 Mine site was being reclaimed.

Seeding of agronomic species is and has usually been the only cost-effective alternative for large-scale reclamation projects in high elevation areas of Alberta. Recognition of factors which influence native species invasion onto sites seeded to agronomic species could provide mine reclamationists with the opportunity to alter reclamation plans to enhance this invasion.

A variety of factors which could potentially affect invasion of native species was measured in conjunction with sampling cover of native species on a minesite north of Grande Cache, Alberta. Covariance analyses were completed with percent cover of native species as dependent variables in order to determine confidence levels for significance

of independent variables and to determine the nature of relationships between independent and dependent variables. Significant independent variables were ranked to determine their relative importance.

Covariance analyses indicated that significant independent variables included coarse fragment rating, northwest versus southeast aspect, distance from the nearest westerly undisturbed area, northeast versus southwest aspect, percent cover of alfalfa and percent slope. Statistically insignificant independent variables included coversoil depth, seeding and fertilization treatment combinations, number of times seeded, number of times fertilized, distance from the nearest undisturbed area, coal waste rating and distance from the southern end of the minesite.

The relationship between coarse fragment rating and native species cover is difficult to interpret. It is not linear and there are few significant differences between rating levels. The number of native species occurrences increases with coarse fragment rating, indicating that native species favor sites with more coarse fragments at the ground surface. Probable reasons for this relationship include decreased competition from agronomic species on sites of higher coarse fragment ratings and improved microsite conditions for native seedling establishment.

Mean percent of coarse fragments at the ground surface was approximately 12.5 percent. Values rarely exceeded 30 percent. Analyses indicated that coarse fragments in the quantities observed on this site enhanced occurrence of native species.

Analyses of the influence of aspect on plant growth on the site indicated that seeded agronomic species have been most successful on easterly aspects. Moss (Dicranum sp.) favors northwest aspects over southeast aspects, as do native species excluding moss. Because native tree, nitrogen-fixing and Asteraceae species failed to significantly favor either northwest or southeast aspects, other native species must be the cause for the 'native species excluding moss' trend. Native species (excluding moss) prefer southwest aspects to northeast aspects, as do Asteraceae species. Nitrogen-fixing species prefer northeast aspects.

Observed aspect trends can be attributed to aspect effects on seed and moisture availability. Southwest aspects are most likely to receive large quantities of wind disseminated spores and seeds, but simultaneously exhibit unfavorable moisture conditions. Northwest aspects probably receive almost as many native species propagules as southwest aspects, but have more favorable moisture conditions as a result of less sun exposure.

Southeast aspects are likely to receive few native propagules and exhibit poor available moisture conditions. No native species groups examined in this study preferred southeast aspects. Northeast aspects are likely to receive few native species propagules but exhibit good available moisture conditions.

Distance from the nearest westerly undisturbed area was significant for all native species groups, and particularly for native tree species. With the exception of moss, all native species declined in cover with increasing distance from the nearest westerly undisturbed area. A factor interaction is suspected to account for the positive relationship between moss cover and this independent variable.

Percent cover of alfalfa appears to significantly affect both moss and Asteraceae species cover. Moss cover declines with increasing alfalfa cover. There is a similar effect for Asteraceae species. Explanations for this effect include excessive shading by alfalfa plants and competition mechanisms. Increased available nitrogen in the vicinity of alfalfa plants may be enhancing the growth of agronomic species, which then outcompete moss and Asteraceae species.

Percent slope affected only moss cover. There was a positive relationship between moss cover and slope.

This relationship can probably be attributed to a combination of reduced coversoil depths, increased coarse fragments at the ground surface and relatively poor soil moisture conditions on steeper slopes. Such conditions are unfavorable to growth of most species found on the site, thus reducing interspecific competition for moss.

Ranking of independent variables indicates that coarse fragment rating is the most important variable contributing to native species cover. Northwest versus southeast aspect and distance from the nearest westerly undisturbed area rank second, followed by percent cover of alfalfa. Percent slope and soil depth rank relatively low.

Overall, variables listed as significant accounted for R-square values of approximately 0.2. This may be sufficient for the reclamation specialist to significantly increase native species cover on similar sites through appropriate manipulation of these variables.

Recommendations for Increasing Native Species Percent Cover

1. Where the ground surface has a cover of coarse fragments of approximately 35 percent or less, no attempt should be made to remove or cover the coarse fragments.
2. If possible during the recontouring process, maximize slope orientation to windward aspects.

3. Where possible, minimize lengths of disturbances parallel to the dominant wind direction to minimize distance from nearest windward seed sources.
4. Where native species seed supplies are inadequate to cover an entire disturbed area, concentrate seeding efforts in areas of low natural seed dispersal potential but adequate soil moisture availability. Establish native seed sources on site by seeding native species in localized areas on windward slopes. Avoid use of competitive agronomic species in these areas where possible.
5. Whenever possible, use competitive agronomic species only where necessary for soil and slope stabilization purposes. This recommendation is based on observations of plant communities on the site and is unsubstantiated by the analyses.
6. Where fertilization will be unavoidable for several years, minimize or eliminate the use of excessively competitive species which tend to become overly dominant on a site when fertilization occurs. Creeping red fescue exhibited this type of behavior on this site, although definitive data were unavailable.

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APPENDICES

APPENDIX I

REDUCED AND FULL MODEL COMPARISONS

Equation

$$F=\frac{(\text{SSE reduced model} - \text{SSE full model})/\text{difference in df}}{\text{MSE full model}}$$

Table 2. Comparison between fourth covariance analysis series (reduced model) and third covariance analysis series (full model).

Dependent Variable	SSE Reduced	SSE Full	Dif. df	MSE Reduced	Full Model Error df	Critical F-value	Calculated F-value
Moss	69794.968	68576.826	5	389.916	174	2.21	0.625
Natives (Excluding Moss)	7504.126	7303.620	5	64.138	112	2.29	0.625
Natives (Including Moss)	81515.759	79900.598	5	450.363	176	2.21	0.717
Native Trees	1380.433	1292.424	5	30.676	40	2.45	0.574
Nitrogen-Fixers	1262.138	771.692	5	78.884	11	3.20	1.243
Native Asteraceae	7.109	3.282	5	0.547	8	3.84	1.400

Table 3. Comparison between fifth covariance analysis series (reduced model) and fourth covariance analysis series (full model).

Dependent Variable	SSE Reduced	SSE Full	Dif. df	MSE Reduced	Full Model Error df	Critical F-value	Calculated F-value
Moss	71421.061	69794.968	3	392.423	179	2.60	1.381
Natives (Excluding Moss)	7713.070	7504.126	3	350.918	117	2.68	0.198
Natives (Including Moss)	84079.284	81515.759	3	456.953	181	2.60	1.870
Native Trees	1511.737	1380.433	3	31.495	45	2.81	1.390
Nitrogen-Fixers	1262.873	1262.138	3	70.160	16	3.24	0.003
Native Asteraceae	9.029	7.109	3	0.564	13	3.41	1.135

Table 4. Comparison between sixth covariance analysis series (reduced model) and fifth covariance analysis series (full model).

Dependent Variable	SSE Reduced	SSE Full	Dif. df	MSE Reduced	Full Model Error df	Critical F-value	Calculated F-value
Moss	72430.459	71421.061	1	395.795	182	3.84	2.551
Natives (Excluding Moss)	7726.189	7713.070	1	63.852	120	3.92	0.205
Natives (Including Moss)	85571.811	84079.284	1	462.550	184	3.84	3.227
Native Trees	1515.147	1511.737	1	30.921	48	4.03	0.110
Nitrogen-Fixers	1298.938	1262.873	1	68.365	18	4.41	0.528
Native Asteraceae	13.777	9.029	1	0.636	16	4.49	7.465

APPENDIX II

SLOPE AND P-VALUE ESTIMATES

Table 5. Slope estimates for the first series of covariance analyses.

	Dependent Variable (% Aerial Cover of Native Species)						
Independent Variable	Natives Excluding Moss	Natives Including Moss	Natives	Trees	N-Fixers	Aster-aceae	Agro nomic Species
N-S Aspect	-7.4962	0.8074	-8.2916	0.2051	-0.5057	0.8715	2.7981
E-W Aspect	3.9737	-0.5375	4.7190	2.1654	-19.7064	3.2564	-7.9856
Distance A	0.0094	-0.0232	-0.0218	-0.0319	-1.2460	0.0424	0.0583
Distance B	0.0079	-0.0290	-0.0108	-0.0259	1.1167	-0.0213	0.0093
Percent Slope	0.1842	0.0151	0.2047	0.0423	-0.6377	-0.0567	-0.0604
Soil Depth	-0.0149	0.1173	0.1292	0.2131	0.2110	0.0271	-0.0820
% Cover Alfalfa	-0.1743	-0.0647	-0.2147	-0.0902	-2.7612	0.0273	1.0173

Table 6. P-value estimates for the first series of covariance analyses.

	Dependent Variable (% Aerial Cover of Native Species)						
Independent Variable	Moss	Natives Excluding Moss	Natives Including Moss	Trees	N-Fixers	Aster-aceae	Agro-nomic Species
Seeding & Fertili-zation Trt. Comb.	0.0547	0.5663	0.8260	0.8915	0.0044	0.6408	0.0328
N-S Aspect	0.0332	0.6661	0.0283	0.9454	0.8583	0.4954	0.3150
E-W Aspect	0.2147	0.7732	0.1724	0.4492	0.0003	0.2939	0.0024
Coarse Fragment Rating	0.0796	0.1246	0.0299	0.4265	0.5441	0.4627	0.0001
Coal Waste Rating	0.1156	0.5445	0.0696	0.8114	0.0018	0.7506	0.4968
Distance A	0.8160	0.2689	0.6188	0.3774	0.0009	0.4618	0.0688
Distance B	0.6858	0.0069	0.6087	0.0854	0.0008	0.6101	0.5565
Percent Slope	0.0865	0.7784	0.0796	0.7067	0.0049	0.4012	0.4674
Soil Depth	0.9517	0.3645	0.6266	0.2968	0.2523	0.8426	0.6831
% Cover Alfalfa	0.1803	0.4498	0.1273	0.6052	0.0007	0.7940	0.0001

Table 7. Slope estimates for the second series of covariance analyses.

	Dependent Variable (% Aerial Cover of Native Species)					
Independent Variable	Moss	Natives Excluding Moss	Natives Including Moss	Trees	N-Fixers	Asteraceae
NW-SE Aspect	-6.2607	-3.0917	-8.4108	-2.7012	-0.4212	-0.1744
Distance B	0.0192	-0.0349	-0.0061	-0.0224	-0.0414	-0.0034
Distance C	-0.0012	-0.0009	-0.0018	-0.0001	0.0022	-0.0002
Percent Slope	0.1329	0.0340	0.1611	-0.0612	0.2562	0.0038
% Cover Alfalfa	-0.1929	-0.0268	-0.2325	-0.0049	-0.1566	-0.0428

Table 8. P-value estimates for the second series of covariance analyses.

	Dependent Variable (% Aerial Cover of Native Species)					
Independent Variable	Moss	Natives Excluding Moss	Natives Including Moss	Trees	N-Fixers	Asteraceae
Coarse Fragment Rating	0.0235	0.0296	0.0148	0.3240	0.4044	0.6791
Coal Waste Rating	0.2020	0.3974	0.1029	0.2749	0.8421	0.4687
NW-SE Aspect	0.0672	0.0909	0.0215	0.2721	0.9427	0.8026
Distance B	0.2428	0.0001	0.7275	0.0227	0.2347	0.4231
Distance C	0.6841	0.5502	0.5738	0.9609	0.6589	0.5464
Percent Slope	0.1886	0.4852	0.1378	0.4212	0.2925	0.8723
% Cover Alfalfa	0.1028	0.7075	0.0670	0.9693	0.6373	0.1276

Table 9. Slope estimates for the third series of covariance analyses.

	Dependent Variable (% Aerial Cover of Native Species)					
Independent Variable	Moss	Natives Excluding Moss	Natives Including Moss	Trees	N-Fixers	Asteraceae
NW-SE Aspect	-5.9400	-2.8106	-8.0722	-2.6010	3.4112	-0.9970
Distance B	0.0167	-0.0373	-0.0086	-0.0275	-0.0500	0.0004
Distance C	0.0005	-0.0004	-0.0001	0.0013	0.0009	-0.0003
Percent Slope	0.1235	0.0323	0.1503	-0.0560	-0.0030	0.0007
% Cover Alfalfa	-0.2300	-0.0586	-0.2707	-0.0685	-0.8478	-0.0102

Table 10. P-value estimates for the third series of covariance analyses.

	Dependent Variable (% Aerial Cover of Native Species)					
Independent Variable	Moss	Natives Excluding Moss	Natives Including Moss	Trees	N-Fixers	Asteraceae
Coarse Fragment Rating	0.0644	0.0394	0.0334	0.5294	0.7310	0.1542
Coal Waste Rating	0.2005	0.3552	0.0980	0.2318	0.5738	0.2734
NW-SE Aspect	0.0906	0.1291	0.0310	0.3376	0.5551	0.1541
Distance B	0.3274	0.0001	0.6335	0.0105	0.1470	0.9114
Distance C	0.8901	0.8133	0.9889	0.5492	0.8780	0.3316
Percent Slope	0.2285	0.5117	0.1721	0.4698	0.9927	0.9692
% Cover Alfalfa	0.0676	0.4673	0.0448	0.6211	0.0716	0.7039
# Times Fertilized	0.1045	0.7066	0.4702	0.6978	0.7993	0.2945
# Times Seeded	0.3450	0.5675	0.3738	0.2501	0.1425	0.2132

Table 11. Slope estimates for the fourth series of covariance analyses.

	Dependent Variable (% Aerial Cover of Native Species)					
Independent Variable	Moss	Natives Excluding Moss	Natives Including Moss	Trees	N-Fixers	Asteraceae
NW-SE Aspect	-6.1813	-3.1009	-8.2869	-2.3448	-2.8390	-0.1699
Distance B	0.0206	-0.0335	-0.0040	-0.0240	-0.0306	-0.0022
% Cover Alfalfa	-0.2009	-0.0283	-0.2407	-0.0011	-0.2009	-0.0375

Table 12. P-value estimates for the fourth series of covariance analyses.

	Dependent Variable (% Aerial Cover of Native Species)					
Independent Variable	Moss	Natives Excluding Moss	Natives Including Moss	Trees	N-Fixers	Asteraceae
Coarse Fragment Rating	0.0114	0.0197	0.0100	0.1798	0.5533	0.3238
Coal Waste Rating	0.2474	0.3580	0.1316	0.2474	0.9954	0.3588
NW-SE Aspect	0.0698	0.0884	0.0232	0.3239	0.5868	0.7919
Distance B	0.1989	0.0001	0.8155	0.0058	0.3382	0.4584
% Cover Alfalfa	0.0863	0.6870	0.0559	0.9931	0.5061	0.1286

Table 13. Slope estimates for the fifth series of covariance analyses.

	Dependent Variable (% Aerial Cover of Native Species)					
Independent Variable	Moss	Natives Excluding Moss	Natives Including Moss	Trees	N-Fixers	Asteraceae
NW-SE Aspect	-6.7984	-3.1530	-8.9575	-1.1877	-2.8261	-0.3059
Distance B	0.0189	-0.0315	-0.0055	-0.0200	-0.0305	-0.0042
% Cover alfalfa	-0.1858	-0.0314	-0.2257	-0.0400	-0.1973	-0.0416

Table 14. P-value estimates for the fifth series of covariance analyses.

	Dependent Variable (% Aerial Cover of Native Species)					
Independent Variable	Moss	Natives Excluding Moss	Natives Including Moss	Trees	N-Fixers	Asteraceae
Coarse Fragment Rating	0.0038	0.0134	0.0035	0.1034	0.4694	0.4359
NW-SE Aspect	0.0448	0.0804	0.0139	0.6026	0.5510	0.5962
Distance B	0.2554	0.0001	0.7461	0.0154	0.3069	0.1379
% Cover Alfalfa	0.1105	0.6522	0.0724	0.7436	0.4826	0.0940

Table 15. Slope estimates for the sixth series of covariance analyses.

	Dependent Variable (% Aerial Cover of Native Species)					
Independent Variable	Moss	Natives Excluding Moss	Natives Including Moss	Trees	N-Fixers	Asteraceae
NW-SE Aspect	-7.7869	-3.1941	-10.1384	-1.2917	-4.2134	-0.2869
Distance B	0.0131	-0.0324	-0.0127	-0.0205	-0.0325	-0.0033

Table 16. P-value estimates for the sixth series of covariance analyses.

	Dependent Variable (% Aerial Cover of Native Species)					
Independent Variable	Moss	Natives Excluding Moss	Natives Including Moss	Trees	N-Fixers	Asteraceae
Coarse Fragment Rating	0.0003	0.0115	0.0002	0.0981	0.4979	0.6241
NW-SE Aspect	0.0202	0.0752	0.0050	0.5639	0.3255	0.6390
Distance B	0.4002	0.0001	0.4477	0.0108	0.2668	0.2574

Table 17. Slope estimates for the seventh series of covariance analyses.

	Dependent Variable (% Aerial Cover of Native Species)					
Independent Variable	Moss	Natives Excluding Moss	Natives Including Moss	Trees	N-Fixers	Asteraceae
NE-SW Aspect	-1.5074	2.1505	0.1805	0.4010	-6.8053	0.5279
Distance B	0.0128	-0.0310	-0.0120	-0.0197	-0.0329	-0.0032

Table 18. P-value estimates for the seventh series of covariance analyses.

	Dependent Variable (% Aerial Cover of Native Species)					
Independent Variable	Moss	Natives Excluding Moss	Natives Including Moss	Trees	N-Fixers	Asteraceae
Coarse Fragment Rating	0.0001	0.0204	0.0001	0.1015	0.7344	0.5256
NE-SW Aspect	0.6128	0.1400	0.9554	0.8023	0.0770	0.1114
Distance B	0.4194	0.0001	0.4815	0.0205	0.2298	0.2328

Table 19. Slope estimates for the eighth series of covariance analyses.

	Dependent Variable (% Aerial Cover of Native Species)					
Independent Variable	Moss	Natives Excluding Moss	Natives Including Moss	Trees	N-Fixers	Asteraceae
NW-SE Aspect	-7.7017	-3.3988	-10.1955	-1.3708	-0.9860	-0.3080
NE-SW Aspect	-0.9924	2.3452	0.7716	0.5211	-6.3792	0.5317
Distance B	0.0129	-0.0313	-0.0126	-0.-196	-0.0319	-0.0032

Table 20. P-value estimates for the eighth series of covariance analyses.

	Dependent Variable (% Aerial Cover of Native Species)					
Independent Variable	Moss	Natives Excluding Moss	Natives Including Moss	Trees	N-Fixers	Asteraceae
Coarse Fragment Rating	0.0003	0.0195	0.0003	0.1198	0.7400	0.5365
NW-SE Aspect	0.0222	0.0575	0.0050	0.5467	0.8317	0.5978
NE-SW Aspect	0.7367	0.1049	0.8081	0.7534	0.1484	0.1174
Distance B	0.4096	0.0001	0.4533	0.0216	0.2619	0.2462

Table 21. Slope estimates for the ninth series of covariance analyses (data base including additional subjectively selected points).

	Dependent Variable (% Aerial Cover of Native Species)					
Independent Variable	Moss	Natives Excluding Moss	Natives Including Moss	Trees	N-Fixers	Asteraceae
NW-SE Aspect	-9.4272	-1.4918	-10.5983	2.8523	1.5241	0.0583
Distance B	0.0136	-0.0242	-0.0100	-0.0042	0.0163	-0.0043

Table 22. P-value estimates for the ninth series of covariance analyses (data base including additional subjectively selected points).

	Dependent Variable (% Aerial Cover of Native Species)					
Independent Variable	Moss	Natives Excluding Moss	Natives Including Moss	Trees	N-Fixers	Asteraceae
Coarse Fragment Rating	0.0002	0.0391	0.0001	0.0309	0.3797	0.0751
NW-SE Aspect	0.0005	0.3359	0.0005	0.2279	0.5793	0.9407
Distance B	0.8203	0.0022	0.5140	0.6707	0.3675	0.4607

Table 23. Slope estimates for the tenth series of covariance analyses (data base including additional subjectively selected points).

	Dependent Variable (% Aerial Cover of Native Species)					
Independent Variable	Moss	Natives Excluding Moss	Natives Including Moss	Trees	N-Fixers	Asteraceae
NE-SW Aspect	-2.0101	0.3106	-1.6430	-0.5073	-4.9850	0.4563
Distance B	0.0142	-0.0232	-0.0077	-0.0071	0.0125	-0.0040

Table 24. P-value estimates for the tenth series of covariance analyses (data base including additional subjectively selected points).

	Dependent Variable (% Aerial Cover of Native Species)					
Independent Variable	Moss	Natives Excluding Moss	Natives Including Moss	Trees	N-Fixers	Asteraceae
Coarse Fragment Rating	0.0001	0.0416	0.0001	0.0464	0.3552	0.0896
NE-SW Aspect	0.4624	0.8244	0.5644	0.8016	0.0601	0.5002
Distance B	0.3124	0.0038	0.6254	0.5035	0.4854	0.4993

Table 25. Slope estimates for the eleventh series of covariance analyses (data base including additional subjectively selected points).

	Dependent Variable (% Aerial Cover of Native Species)					
Independent Variable	Moss	Natives Excluding Moss	Natives Including Moss	Trees	N-Fixers	Asteraceae
NW-SE Aspect	-9.3905	-1.5760	-10.6205	2.8084	3.0486	0.1067
NE-SW Aspect	-1.3084	0.4565	-0.9101	-0.4990	-5.7477	0.4598
Distance B	0.0124	-0.0241	-0.0110	-0.0055	0.0117	-0.0039

Table 26. P-value estimates for the eleventh series of covariance analyses (data base including additional subjectively selected points).

	Dependent Variable (% Aerial Cover of Native Species)					
Independent	Moss	Natives Excluding Moss	Natives Including Moss	Trees	N-Fixers	Asteraceae
Coarse Fragment Rating	0.0002	0.0455	0.0001	0.0317	0.2627	0.0983
NW-SE Aspect	0.0006	0.3139	0.0006	0.2368	0.2703	0.8926
NE-SW Aspect	0.5979	0.7457	0.7449	0.8044	0.0365	0.5036
Distance B	0.3674	0.0028	0.4757	0.6050	0.5111	0.5084

APPENDIX III

ANALYSIS OF COVARIANCE TABLES

First Series of Covariance Analyses

Table 27. Covariance analysis of moss percent cover.

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	24	20287.8387	845.3266	2.15	0.0028	0.2400	72.4628
Error	164	64606.1041	393.9397				
Total	188	84894.9429					

Table 28. Covariance analysis of native species percent cover (excluding moss).

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	23	2809.1411	122.1366	1.79	0.0249	0.2861	169.0344
Error	103	7009.4397	68.0528				
Total	126	9818.5808					

Table 29. Covariance analysis of native species percent cover (including moss).

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	24	24800.2871	1033.3453	2.22	0.0018	0.2431	71.0668
Error	166	77218.5300	465.1719				
Total	126	102018.8172					

Table 30. Covariance analysis of native tree species percent cover.

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	25	930.7011	37.2280	0.96	0.5339	0.4538	184.5701
Error	29	1120.1600	38.6262				
Total	54	2050.8611					

Table 31. Covariance analysis of native nitrogen-fixing species percent cover.

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	20	1582.9101	79.1455	25.98	0.0031	0.9924	28.7851
Error	4	12.1875	3.0469				
Total	24	1595.0976					

Table 32. Covariance analysis of native Asteraceae species percent cover.

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	20	12.2948	0.6147	0.83	0.6791	0.8924	101.0347
Error	2	1.4826	0.7413				
Total	22	13.7774					

Second Series of Covariance Analyses

Table 33. Covariance analysis of moss percent cover.

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	11	15796.5775	1436.0525	3.68	0.0001	0.1861	72.1347
Error	177	69097.3653	390.3806				
Total	188	84893.9429					

Table 34. Covariance analysis of native species percent cover (excluding moss).

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	11	2369.2634	215.3876	3.33	0.0005	0.2413	164.9155
Error	115	7449.3174	64.7767				
Total	126	9818.5808					

Table 35. Covariance analysis of native species percent cover (including moss).

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	11	21554.6988	1959.5181	4.36	0.0001	0.2113	69.8610
Error	179	80464.1183	449.5202				
Total	190	102018.8172					

Table 36. Covariance analysis of native tree species percent cover.

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	11	692.8398	62.9854	1.99	0.0531	0.3378	166.8940
Error	43	1358.0213	31.5819				
Total	54	2050.8611					

Table 37. Covariance analysis of native nitrogen-fixing species percent cover.

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	10	432.5735	43.2574	0.52	0.8485	0.2712	150.2719
Error	14	1162.5241	83.1374				
Total	24	1595.0976					

Table 38. Covariance analysis of native Asteraceae species percent cover.

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	11	6.9314	0.6301	1.01	0.4920	0.5031	92.5747
Error	11	6.8460	0.6224				
Total	22	13.7774					

Third Series of Covariance Analyses

Table 39. Covariance analysis of moss percent cover.

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	14	16317.1172	1165.5084	2.96	0.0005	0.1922	72.4794
Error	174	68576.8257	394.1197				
Total	188	84893.9429					

Table 40. Covariance analysis of native species percent cover (excluding moss).

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	14	2514.9607	179.6401	2.75	0.0015	0.2561	165.4673
Error	112	7303.6200	65.2109				
Total	126	9818.5808					

Table 41. Covariance analysis of native species percent cover (including moss).

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	14	22118.2191	1579.8728	3.48	0.0001	0.2168	70.2067
Error	176	79900.5981	453.9807				
Total	190	102018.8172					

Table 42. Covariance analysis of native tree species percent cover.

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	14	758.4376	54.1741	1.68	0.1003	0.3698	168.8084
Error	40	1292.4235	32.3106				
Total	54	2050.8611					

Table 43. Covariance analysis of native nitrogen-fixing species percent cover.

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	13	823.4057	63.3389	0.90	0.5750	0.5162	138.1231
Error	11	771.6919	70.1538				
Total	24	1595.0976					

Table 44. Covariance analysis of native Asteraceae species percent cover.

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	14	10.4954	0.7497	1.83	0.1973	0.7618	75.1617
Error	8	3.2820	0.4103				
Total	22	13.7774					

Fourth Series of Covariance Analyses

Table 45. Covariance analysis of moss percent cover.

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	9	15098.9752	1677.6639	4.30	0.0001	0.1779	72.0918
Error	179	69794.9676	389.9160				
Total	188	84893.9429					

Table 46. Covariance analysis of native species percent cover (excluding moss).

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	9	2314.4544	257.1616	4.01	0.0002	0.2357	164.1003
Error	117	7504.1264	64.1378				
Total	126	9818.5808					

Table 47. Covariance analysis of native species percent cover (including moss).

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	9	20503.0583	2278.1176	5.06	0.0001	0.2010	69.9265
Error	181	81515.7588	450.3633				
Total	190	102018.8172					

Table 48. Covariance analysis of native tree species percent cover.

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	9	670.4283	74.4920	2.43	0.0241	0.3269	164.4838
Error	45	1380.4328	30.6763				
Total	54	2050.8611					

Table 49. Covariance analysis of native nitrogen-fixing species percent cover.

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	8	332.9592	41.6199	0.53	0.8190	0.2087	146.4651
Error	16	1262.1384	78.8836				
Total	24	1595.0976					

Table 50. Covariance analysis of native Asteraceae species percent cover.

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	9	6.6684	0.7409	1.35	0.2997	0.4840	86.7768
Error	13	7.1090	0.5468				
Total	22	13.7774					

Fifth Series of Covariance Analyses

Table 51. Covariance analysis of moss percent cover.

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	6	13472.8816	2245.4803	5.72	0.0001	0.1587	72.3232
Error	182	71421.0613	392.4234				
Total	188	84893.9429					

Table 52. Covariance analysis of native species percent cover (excluding moss).

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	6	2105.5105	350.9184	5.46	0.0001	0.2144	164.2764
Error	120	7713.0703	64.2756				
Total	126	9818.5808					

Table 53. Covariance analysis of native species percent cover (including moss).

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	6	17939.5335	2989.9223	6.54	0.0001	0.1758	70.4362
Error	184	84079.2836	456.9526				
Total	190	102018.8172					

Table 54. Covariance analysis of native tree species percent cover.

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	6	539.1241	89.8540	2.85	0.0186	0.2629	166.6630
Error	48	1511.7370	31.4945				
Total	54	2050.8611					

Table 55. Covariance analysis of native nitrogen-fixing species percent cover.

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	6	332.2244	55.3707	0.79	0.5899	0.2083	138.1289
Error	18	1262.8732	70.1596				
Total	24	1595.0976					

Table 56. Covariance analysis of native Asteraceae species percent cover.

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	6	4.7488	0.7915	1.40	0.2733	0.3447	88.1500
Error	16	9.0286	0.5643				
Total	22	13.7774					

Sixth Series of Covariance Analyses

Table 57. Covariance analysis of moss percent cover.

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	5	12463.4821	2492.6968	6.30	0.0001	0.1468	72.6333
Error	183	72430.4587	395.7949				
Total	188	84893.9429					

Table 58. Covariance analysis of native species percent cover (excluding moss).

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	5	2092.3919	418.4784	6.55	0.0001	0.2131	163.7352
Error	121	7726.1889	63.8528				
Total	126	9818.5807					

Table 59. Covariance analysis of native species percent cover (including moss).

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	5	16447.0061	3289.4012	7.11	0.0001	0.1612	70.8663
Error	185	85571.8111	462.5503				
Total	190	102018.8172					

Table 60. Covariance analysis of native tree species percent cover.

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	5	535.7143	107.1429	3.47	0.0093	0.2612	165.1395
Error	49	1515.1468	30.9214				
Total	54	2050.8611					

Table 61. Covariance analysis of native nitrogen-fixing species percent cover.

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	5	296.1597	59.2319	0.87	0.5215	0.1857	136.3510
Error	19	1298.9379	68.3651				
Total	24	1595.0976					

Table 62. Covariance analysis of native Asteraceae species percent cover.

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	5	2.9603	0.5921	0.93	0.4857	0.2149	93.6057
Error	17	10.8171	0.6363				
Total	22	13.7774					

Seventh Series of Covariance Analyses

Table 63. Covariance analysis of moss percent cover.

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	5	10393.6201	2078.7240	5.11	0.0002	0.1224	73.6638
Error	183	74500.3228	407.1056				
Total	188	84893.9429					

Table 64. Covariance analysis of native species percent cover (excluding moss).

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	5	2028.7946	405.7589	6.30	0.0001	0.2066	164.4077
Error	121	7789.7862	64.3784				
Total	126	9818.5808					

Table 65. Covariance analysis of native species percent cover (including moss).

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	5	12717.1720	2543.4344	5.27	0.0002	0.1247	72.3942
Error	185	89301.6452	482.7116				
Total	190	102018.8171					

Table 66. Covariance analysis of native tree species percent cover.

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	5	527.2494	105.4499	3.39	0.0104	0.2571	165.6002
Error	49	1523.6117	31.0941				
Total	52	2050.8611					

Table 67. Covariance analysis of native nitrogen-fixing species percent cover.

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	5	439.1946	87.8389	1.44	0.2542	0.2753	128.6248
Error	19	1155.9030	60.8370				
Total	24	1595.0976					

Table 68. Covariance analysis of native Asteraceae species percent cover.

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	5	4.3745	0.8749	1.58	0.2184	0.3175	87.2726
Error	17	9.4029	0.5531				
Total	22	13.7774					

Eighth Series of Covariance Analyses

Table 69. Covariance analysis of moss percent cover.

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	6	12508.5760	2084.7627	5.24	0.0001	0.1473	72.8098
Error	182	72385.3669	397.7218				
Total	188	84893.9429					

Table 70. Covariance analysis of native species percent cover (excluding moss).

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	6	2260.4890	376.7482	5.98	0.0001	0.2302	162.6176
Error	120	7558.0918	62.9841				
Total	126	9818.5808					

Table 71. Covariance analysis of native species percent cover (including moss).

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	6	16474.5097	2745.7516	5.91	0.0001	0.1615	71.0472
Error	184	85544.3075	464.9147				
Total	190	102018.8172					

Table 72. Covariance analysis of native tree species percent cover.

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	6	538.8583	89.8097	2.85	0.0186	0.2627	166.6777
Error	48	1512.0028	31.5001				
Total	54	2050.8611					

Table 73. Covariance analysis of native nitrogen-fixing species percent cover.

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	6	442.1742	73.6957	1.15	0.3744	0.2772	131.9790
Error	18	1152.9234	64.0513				
Total	24	1595.0976					

Table 74. Covariance analysis of native Asteraceae species percent cover.

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	6	4.5417	0.7570	1.31	0.3078	0.3297	89.1550
Error	16	9.2356	0.5772				
Total	22	13.7774					

Ninth Series of Covariance Analyses (Additional Data Set)

Table 75. Covariance analysis of moss percent cover.

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	5	14559.7071	2911.9414	7.63	0.0001	0.1320	70.5169
Error	251	95765.1028	381.5343				
Total	256	110324.8100					

Table 76. Covariance analysis of native species percent cover (excluding moss).

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	5	1611.6386	322.3280	3.60	0.0039	0.0878	142.4029
Error	187	16752.6217	89.5861				
Total	192	18364.2603					

Table 77. Covariance analysis of native species percent cover (including moss).

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	5	21620.7995	4324.1599	8.72	0.0001	0.1451	69.6887
Error	257	127371.0521	495.6072				
Total	262	148991.8515					

Table 78. Covariance analysis of native tree species percent cover.

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	5	814.5215	162.9043	2.00	0.0857	0.0991	152.4292
Error	91	7403.8587	81.3611				
Total	96	8218.3802					

Table 79. Covariance analysis of native nitrogen-fixing species percent cover.

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	5	387.3701	77.4740	0.79	0.5583	0.0685	115.4452
Error	54	5265.2192	97.5041				
Total	59	5652.5893					

Table 80. Covariance analysis of native Asteraceae species percent cover.

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	5	41.6064	8.3213	1.87	0.1249	0.2160	149.9899
Error	34	150.9926	4.4410				
Total	39	192.5990					

Tenth Series of Covariance Analyses (Additional Data Set)

Table 81. Covariance analysis of moss percent cover.

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	5	10123.4787	2024.6957	5.07	0.0002	0.0918	72.1317
Error	251	100201.3313	399.2085				
Total	256	110324.8100					

Table 82. Covariance analysis of native species percent cover (excluding moss).

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	5	1518.1259	303.6252	3.37	0.0061	0.0827	142.7998
Error	187	16846.1344	90.0863				
Total	192	183642.2603					

Table 83. Covariance analysis of native species percent cover (including moss).

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	5	15813.5271	3162.7054	6.10	0.0001	0.1061	71.2597
Error	257	133178.3244	518.2036				
Total	262	148991.8516					

Table 84. Covariance analysis of native tree species percent cover.

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	5	701.2239	140.2448	1.70	0.1431	0.0853	153.5911
Error	91	7517.1563	82.6061				
Total	96	8218.3802					

Table 85. Covariance analysis of native nitrogen-fixing species percent cover.

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	5	691.8741	138.3748	1.51	0.2032	0.1224	112.0572
Error	54	4960.7152	91.8651				
Total	59	5652.5893					

Table 86. Covariance analysis of native Asteraceae species percent cover.

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	5	42.9171	8.5834	1.95	0.1117	0.2228	149.3375
Error	34	149.6819	4.4024				
Total	39	192.5990					

Eleventh Series of Covariance Analyses (Additional Data Set)

Table 87. Covariance analysis of moss percent cover.

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	6	14743.4940	2457.2490	6.43	0.0001	0.1336	70.5899
Error	250	95581.3159	382.3253				
Total	256	110324.8100					

Table 88. Covariance analysis of native species percent cover (excluding moss).

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	6	1609.9609	268.3268	2.98	0.0084	0.0877	142.7924
Error	186	16754.2994	90.0769				
Total	192	18364.2603					

Table 89. Covariance analysis of native species percent cover (including moss).

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	6	21870.1768	3645.0295	7.34	0.0001	0.1468	69.7563
Error	256	127121.6747	496.5690				
Total	262	148991.8516					

Table 90. Covariance analysis of native tree species percent cover.

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	6	817.8596	136.3100	1.66	0.1406	0.0995	153.2391
Error	90	7400.5206	82.2280				
Total	96	8218.3802					

Table 91. Covariance analysis of native nitrogen-fixing species percent cover.

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	6	805.3785	134.2298	1.47	0.2072	0.1425	111.8079
Error	53	4847.2108	81.4568				
Total	59	5652.5893					

Table 92. Covariance analysis of native Asteraceae species percent cover.

Source	df	Sum of Squares	Mean Square	F-value	P-value	R-square	CV
Model	6	43.0011	7.1669	1.58	0.1838	0.2233	151.5407
Error	33	149.5979	4.5333				
Total	39	192.5990					

APPENDIX IV

LEAST SIGNIFICANT DIFFERENCE TESTS

Fifth Series of Covariance Analyses

Table 93. Least significant difference test for moss percent cover.

Coarse Fragment Rating Comparison	Lower Confidence Limit	Difference Between Means	Upper Confidence Limit	
0-1	0.710	19.413	38.116	***
0-2	-12.579	5.628	23.835	
0-3	-18.359	-0.271	17.817	
1-0	-38.116	-19.413	-0.710	***
1-2	-21.846	-13.785	-5.724	***
1-3	-27.473	-19.684	-11.895	***
2-0	-23.835	-5.628	12.579	
2-1	5.724	13.785	21.846	***
2-3	-12.408	-5.899	0.610	
3-0	-17.817	0.271	18.359	
3-1	11.895	19.684	27.473	***
3-2	-0.610	5.899	12.408	

*** = Comparison significant at alpha=.05 level.
df=183 MSE=395.795 Critical T=1.97301

Table 94. Least significant difference test for native species percent cover (excluding moss).

Coarse Fragment Rating Comparison	Lower Confidence Limit	Difference Between Means	Upper Confidence Limit	
0-1	2.207	10.312	18.418	***
0-2	-1.200	6.220	13.640	
0-3	2.530	9.914	17.298	***
1-0	-18.418	-10.312	-2.207	***
1-2	-8.636	-4.092	0.451	
1-3	-4.883	-0.398	4.086	
2-0	-13.640	-6.220	1.200	
2-1	-0.451	4.092	8.636	
2-3	0.616	3.694	6.772	***
3-0	-17.298	-9.914	-2.530	***
3-1	-4.086	0.398	4.883	
3-2	-6.772	-3.694	-0.616	***

*** = Comparison significant at alpha=.05 level.
df=121 MSE=63.8528 Critical T=1.97976

Table 95. Least significant difference test for native species percent cover (including moss).

Coarse fragment Rating Comparison	Lower Confidence Limit	Difference Between Means	Upper Confidence Limit	
0-1	5.327	23.967	42.606	***
0-2	-12.274	5.818	23.911	
0-3	-15.030	2.922	20.874	
1-0	-42.606	-23.967	-5.327	***
1-2	-26.789	-18.148	-9.508	***
1-3	-29.387	-21.044	-12.702	***
2-0	-23.911	-5.818	12.274	
2-1	9.508	18.148	26.789	***
2-3	-9.932	-2.896	4.140	
3-0	-20.874	-2.922	15.030	
3-1	12.702	21.044	29.387	***
3-2	-4.140	2.896	9.932	

*** = Comparison significant at alpha=.05 level.
df=185 MSE=462.55 Critical T=1.97297

Table 96. Least significant difference test for native tree species percent cover.

Coarse Fragment Rating Comparison	Lower Confidence Limit	Difference Between Means	Upper Confidence Limit	
0-1	1.206	13.700	26.194	***
0-2	-1.123	10.314	21.752	
0-3	2.476	13.841	25.207	***
1-0	-26.194	-13.700	-1.206	***
1-2	-9.482	-3.386	2.711	
1-3	-5.819	0.141	6.102	
2-0	-21.752	-10.314	1.123	
2-1	-2.711	3.386	9.482	
2-3	0.325	3.527	6.729	***
3-0	-25.207	-13.841	-2.476	***
3-1	-6.102	-0.141	5.819	
3-2	-6.729	-3.527	-0.325	

*** = Comparison significant at alpha=.05 level.
df=49 MSE=30.9214 Critical T=2.00958

Table 97. Least significant difference test for native nitrogen-fixing species percent cover.

Coarse Fragment Rating Comparison	Lower Confidence Limit	Difference Between Means	Upper Confidence Limit
0-1	-22.850	-2.867	17.116
0-2	-25.299	-7.386	10.527
0-3	-23.444	-4.943	13.558
1-0	-17.116	2.867	22.850
1-2	-15.529	-4.519	6.491
1-3	-14.018	-2.076	9.866
2-0	-10.527	7.386	25.299
2-1	-6.491	4.519	15.529
2-3	-5.568	2.443	10.454
3-0	-13.558	4.943	23.444
3-1	-9.866	2.076	14.018
3-2	-10.454	-2.443	5.568

*** = Comparison significant at alpha=.05 level.
df=19 MSE=68.3652 Critical T=2.09302

Table 98. Least significant difference test for native Asteraceae species percent cover.

Coarse Fragment Rating Comparison	Lower Confidence Limit	Difference Between Means	Upper Confidence Limit
0-1	-0.6075	0.8500	2.3075
0-2	-0.5305	0.8000	2.1305
0-3	-0.2379	1.0778	2.3934
1-0	-2.3075	-0.8500	0.6075
1-2	-1.0806	-0.0500	0.9806
1-3	-0.7836	0.2278	1.2391
2-0	-2.1305	-0.8000	0.5305
2-1	-0.9806	0.0500	1.0806
2-3	-0.5400	0.2778	1.0956
3-0	-2.3934	-1.0778	0.2379
3-1	-1.2391	-0.2278	0.7836
3-2	-1.0956	-0.2778	0.5400

*** = Comparison significant at alpha = .05 level.
df=17 MSE=0.6369 Critical T=2.10982

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